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SOLE SOURCE AQUIFER PETITION

FOR THE

MISSOULA VALLEY AQUIFER

Prepared and Submitted by the
Environmental Health Division
of the
Missoula City County Health Department

MISSOULA CITY-COUNTY HEALTH DEPARTMENT

301 WEST ALDER
MISSOULA, MONTANA 59802

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Water Management Division

PETITIONER IDENTIFICATION

AQUIFER	Name	Missoula Aquifer
	Location	Missoula, Montana
PETITIONER	Name	Missoula City-County Health Department
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. PETITIONER INFORMATION

Executive Summary

The Missoula City-County Health Department is petitioning the EPA to designate the Missoula Aquifer a "Sole Source Aquifer" as provided for in the Federal Safe Drinking Water Act Amendments of 1986.

The Missoula Health Department is an agency supported and funded by the City and County of Missoula. The Environmental Health Division is responsible for preventing environmental damage and degradation.

Linda Hedstrom, Director of Environmental Health, is the responsible person for the petitioner. Jon Shannon and Dan Corti, Environmental Health Specialists, are contacts who can clarify the petition contents and supply additional information if needed.

A. Petitioner Information

The Missoula City-County Health Department (MCCHD) is petitioning the Environmental Protection Agency to designate the Missoula Aquifer as a Sole Source Aquifer (SSA). The Missoula Aquifer is located in western Montana, approximately two hundred miles east of Spokane, Washington and one hundred miles west of Helena, Montana. The boundaries of the aquifer lie within the state of Montana and completely within Missoula County. The aquifer lies within Townships 13, 14, and part of 15 North and Ranges 19, 20, and 21 west of the Principal Meridian, Montana. Missoula County's population is 77,400 with approximately 65,000 (or 84 percent) residing above the Missoula Aquifer, most of these within the Missoula city limits.

The Missoula City-County Health Department is an agency jointly funded and supported by the City and County of Missoula through an Intergovernmental Agreement and charged with protecting the health and welfare of Missoula City and County citizens. The Environmental Health Division, one of four divisions in the Health Department, is responsible for preventing environmental damage and degradation in the community through developing and implementing comprehensive environmental health programs. Within the Environmental Health Division, the Director, Linda Hedstrom, and two Environmental Health Specialists, Dan Corti and Jon Shannon, are representing the Department in pursuit of the Sole Source Designation and will serve as contacts to EPA in the petition process.

II. DESCRIPTION OF THE MISSOULA AQUIFER AND VALLEY

Executive Summary

The Missoula Valley is a wide alluvial mountain valley located in West-central Montana. The Valley trends N55°W and is approximately 20 miles long and from 8 to 1 miles wide. The Missoula Aquifer lies beneath the Valley and is roughly defined by the topographic break in slope of the surrounding mountains.

The stratigraphy of the Valley consists of three major subdivisions. The oldest formation is the Precambrian Belt Supergroup metasediments which form a shallow bowl in cross-section. This bowl is filled with nearly 2000 feet of sediments from the Tertiary period that consist of fine grained material interbedded with discontinuous layers of sand and gravel. The youngest formation is a thin layer of Miocene to recent coarse sands and gravels overlying the older Tertiary sediments and is known locally as the Missoula Aquifer. These coarse alluvial sediments are generally less than 200 feet thick and the saturated portion yields large quantities of good quality water to area wells.

The Missoula Aquifer is currently the only source of drinking water for Missoula valley residents and supplies 80% of the residents in Missoula County with drinking water. The remainder of County residents live outside the Missoula Valley and receive their drinking water from a variety of surface and groundwater sources. Individual wells, two municipal water systems, over 30 small community water systems, and several large industrial users all rely upon water from the aquifer. The Missoula Health Department is interested in obtaining a Sole Source Aquifer designation as a first step in a local comprehensive water quality management program designed to ensure that the current and future users will have a reliable source of good quality water into the future.

Thin, coarse sediments overlying a shallow water table makes the Missoula Aquifer vulnerable to contamination. Septic systems, industrial waste ponds, landfills, storm water runoff, underground storage tanks, and pipelines are potential direct sources of contamination to the Aquifer. Several incidents over the last five years have led to the contamination of portions of the Aquifer. Because of the high vulnerability of the Aquifer to contamination, and the presence of potential sources of contamination overlying the aquifer, special groundwater management is needed.

Several studies of chemical and bacterial water quality during the last decade have shown the aquifer contains very good quality water. Some elevated cases of nitrate and bacterial levels have been detected, but are believed to be localized problems associated with improper well construction and septic waste disposal.

The pH of Aquifer water ranges from 6.8 to 8.5. Hardness ranges from 138 to 210 and the concentration of total dissolved solids averages less than 500 mg/L.

A. General Description of Aquifer and Valley

Located in western Montana (see Figure 1) the Missoula Aquifer consists of young alluvial sediments of Early Miocene to Recent age trapped within a wide alluvial mountain valley (Missoula valley). The valley extends from the city of Missoula on the eastern end to the town of Huson approximately 20 miles to the northwest. From an aerial view, the valley is eight miles wide at its widest extent and tapers to about one mile in width near its western end at Huson. The boundary of the aquifer closely follows the limit of the valley floor and is defined by the topographic break of the surrounding terraces and mountain slopes (see Figure 2).

The diagrammatic cross-section in Figure 3 shows the stratigraphic relationship of the Missoula valley geology. The oldest formation, Precambrian Belt Supergroup Metasediments, represents a shallow bowl in section. The bowl is filled with nearly 2000 feet of Tertiary (late Eocene to early Miocene) sediments, predominantly silts with interbedded and inter-fingered layers of sand and gravel. The youngest formation represents a thin layer (less than 200 feet) of Miocene to Recent coarse sand and gravel covering the Tertiary sediments. All three of these formations yield various quantities of groundwater; however, the Miocene to Recent coarse sand and gravel (Missoula Aquifer) are the most prolific and the main source of groundwater within the valley. Well drillers typically encounter the high productivity of the coarse sediments of the Missoula Aquifer and fail to explore deeper and older sediments.

The Missoula Aquifer represents a complex arrangement of fluvial, lacustrine, and colluvial sediments. The aquifer can generally be subdivided into three smaller hydrostratigraphic units: an upper coarse sand and gravel unit, a finer layer of mixed sand, silt and clay, and a lower coarse sand and gravel unit. The units occur sporadically throughout the valley in discontinuous layers and lenses only to reveal this generalized pattern. The majority of wells are finished within the lower hydro-

WESTERN MONTANA
General Locations

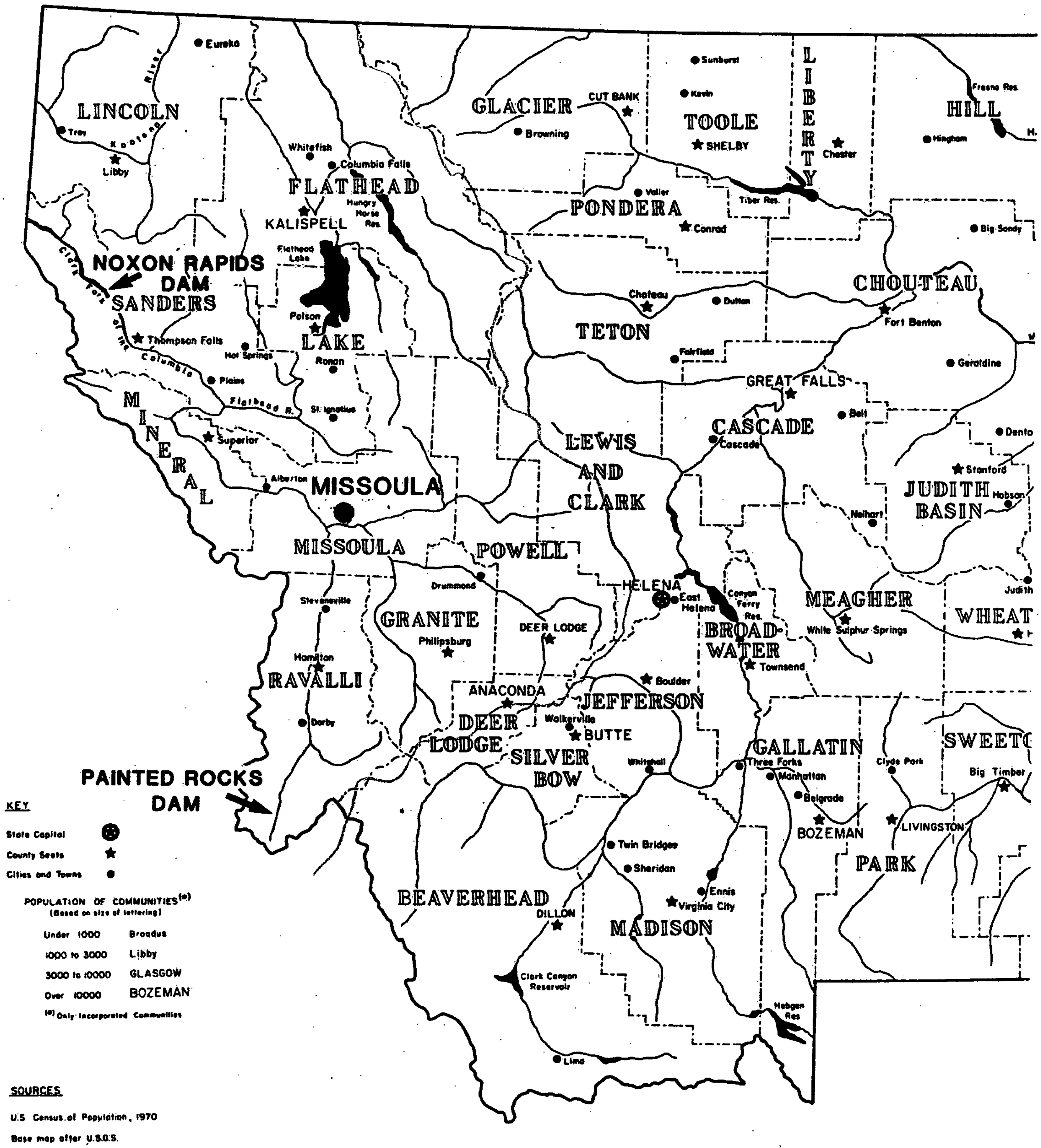
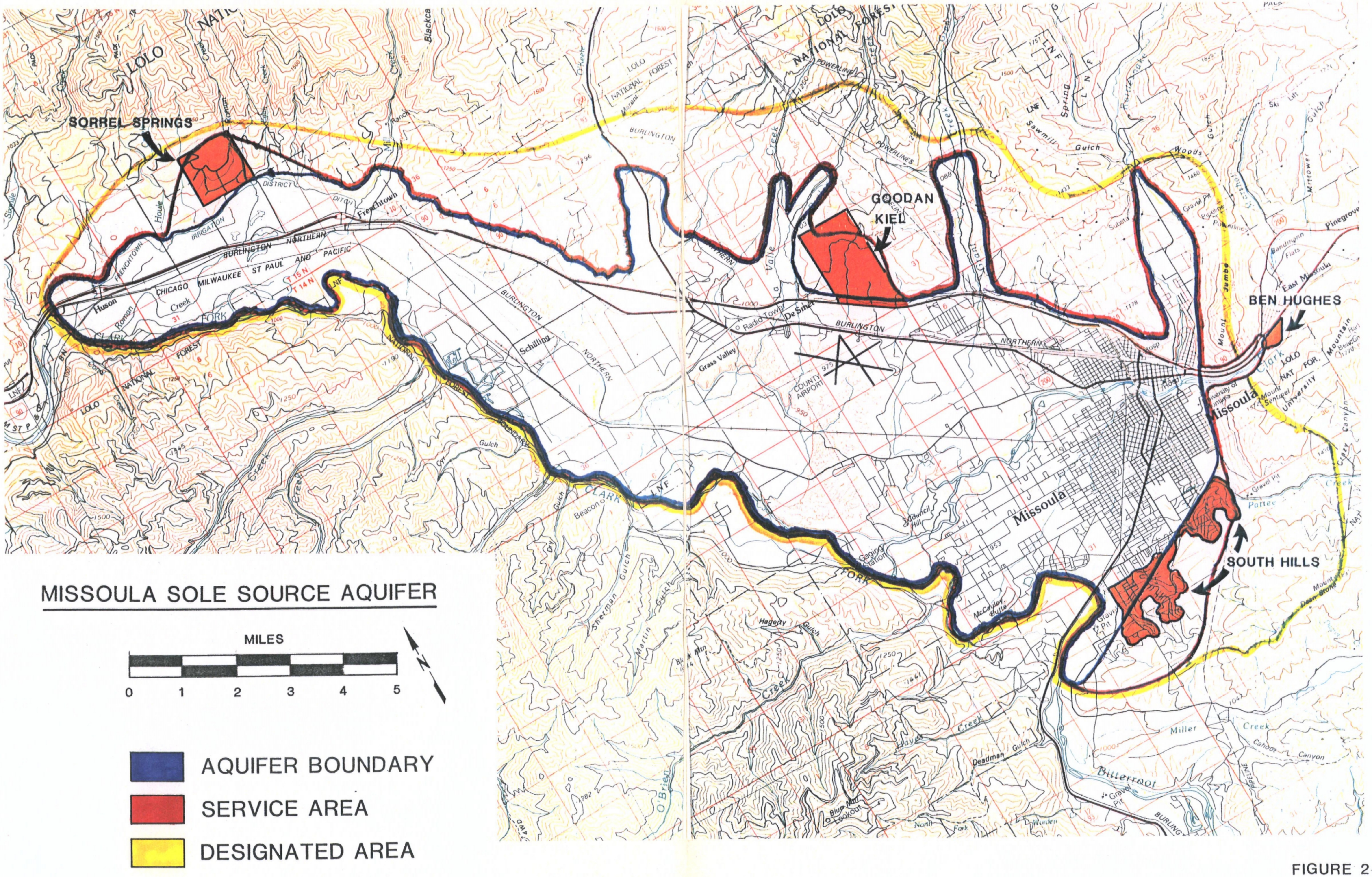


FIGURE 1



MISSOULA SOLE SOURCE AQUIFER
MILES
0 1 2 3 4 5
N
AQUIFER BOUNDARY
SERVICE AREA
DESIGNATED AREA
SORREL SPRINGS
GOODAN KIEL
BEN HUGHES
SOUTH HILLS
Missoula
Frenchtown
Huson
LOLO NATIONAL FOREST
BURLINGTON NORTHERN
CHICAGO MILWAUKEE ST PAUL AND PACIFIC
COUNTY AIRPORT
Grass Valley
Bitterroot

FIGURE 2

CROSS SECTION OF MISSOULA VALLEY

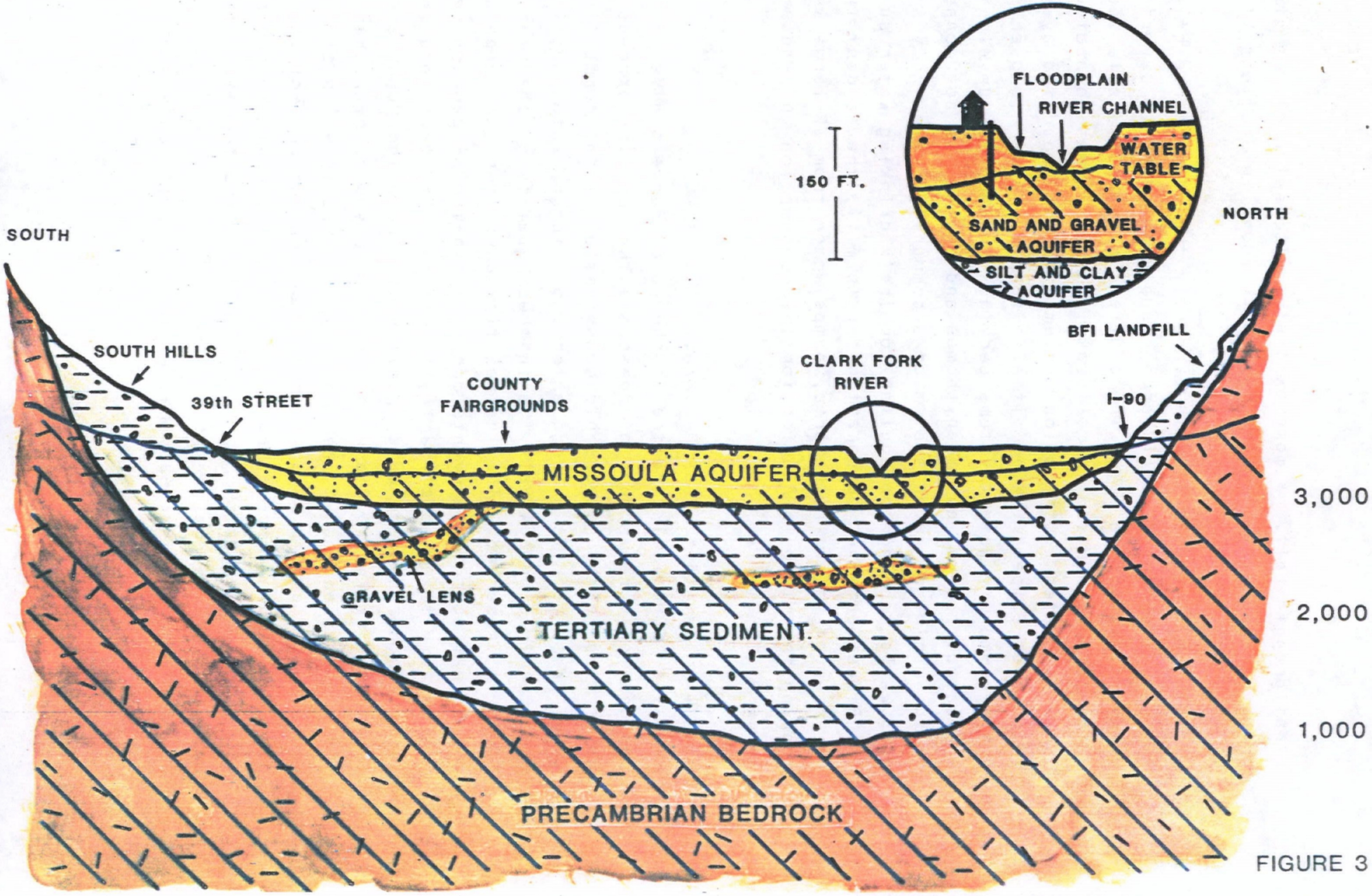


FIGURE 3

stratigraphic unit. A more extensive discussion of the stratigraphy and aquifer characteristics is found in Sections VIII to X.

The Missoula Aquifer is currently the only source of drinking water for the Missoula area, supplying water to a variety of users within the valley. The aquifer is used as a sole source of water for urban Missoula residents and businesses connected to a municipal water distribution system owned and operated by Mountain Water Company (MWC). It also supplies water to over 30 small community water systems serving residential developments throughout the valley. Many homes and businesses not connected to the municipal water system or a community system rely solely upon wells tapping the aquifer for their drinking water supply. The Stone Container Corporation's pulp mill, the largest individual user of water in the area, pumps water from 12 large wells tapping the Missoula Aquifer for the consumption and industrial needs of the mill.

B. Interest in the SSA Designation

The MCCHD is interested in the sole source aquifer designation for a number of reasons. The petition process is a major step in the responsible conservation of the community's water resource. To a large extent, our future water quality will be determined by how well the instream quality of the Clark Fork River is preserved. The instreamflow parameters are dependent on the stream source and events occurring in the stream source area. The ability to at least partially ensure that stream source events do not degrade water quality will help the MCCHD and the community retain the Clark Fork as a safe source of recharge for the Missoula aquifer. The smaller sidestreams, which also help recharge the aquifer, merit both attention and protection. The possibility of toxic or hazardous wastes entering the groundwater from directly above the aquifer also present a threat that is only partially addressed at this time.

The community already has a high level of concern about water quality issues. Several localized incidents of contamination of groundwater have made Missoula residents aware that water is not an infinite resource that can be taken for granted. Some of these incidents are described in section IIC. The Milltown Superfund project focused attention on the large volume of hazardous waste that has accumulated behind the Milltown dam. Arsenic from upstream mining operations settled with the sediments behind the dam. In May of 1981, four community water wells (affecting 33 households) showed elevated levels of arsenic. In June of 1985, an EPA-funded replacement water system came on line. The length of the process and the magnitude of the remaining problem (what to do with the remaining sediments behind the dam) still captures media attention. Montana Power Company, a local utility purveyor, is trying to gain approval to reconstruct the Milltown dam. The potential impacts of a sudden release of sediments into the Clark Fork immediately above Missoula are another current controversy involving our ground and surface water.

The hope of the MCCHD is to change the focus of water quality issues in Missoula from a reactive to a proactive position. The SSA petition process is already providing impetus in that direction. The collection and correlation of the data contained in this petition have been enlightening and useful. The entire process of obtaining the SSA designation will be a cornerstone in the larger process of increasing public support for responsible use of the land above the aquifer and the resultant protection of the aquifer as a resource.

C. Aquifer Vulnerability

The wide alluvial valley that contains the Missoula Aquifer is typical of mountain valleys in the Rocky Mountain Region. The recent alluvium that fills the valley is underlain by layers of permeable sedimentary deposits and Precambrian Metamorphic bedrock. Surficial deposits are generally coarse grained, although lacustrine silts are present in some areas. Groundwater depths are typically shallow. Dutton (1981) described a generalized cross-section of the valley's soils with respect to their distance from the Clark Fork River. (This cross-section is shown as Figure 4.)

The relative vulnerability of an aquifer to contamination is dependent on several factors. The most important of these factors include: the depth to groundwater; the nature of the geological material of the surface, vadose and saturated zones; the hydraulic conductivity and rate of recharge; and to a lesser extent the topography and climate.

In the Missoula Aquifer depth to groundwater ranges from 0 feet in some swales to depths greater that 100 feet in some Glacial Lake Missoula clay deposits. Soils over the aquifer are generally sandy to gravelly loams. The vadose zone consists of clean to silty sand and gravel. The slope of the valley floor ranges from 1-8 percent and is generally quite level. Hydraulic conductivity and recharge values are discussed later in the report (see Section IX C.), but are generally quite high.

The Missoula Aquifer, with thin, coarse soils and shallow groundwater, is very vulnerable to contamination. Like other wide alluvial Rocky Mountain valley aquifers, especially those on the Western flanks where precipitation is higher and depth to groundwater is shallower, special management is needed to prevent degradation of groundwater quality.

Natural attenuation processes, such as sorption, buffering and neutralization, ion-exchange, and biodegradation, are limited where soils are thin and coarse. Contaminants introduced both from the surface and through subsurface sources, move quickly through the unsaturated zone and remain largely unchanged. Ver Hay (1987) reported that septic system drain fields installed in gravelly soils are degrading the aquifer with bacterial and chemical contaminants, and that the vadose zone in these soils was not providing the treatment required to protect the groundwater.

Protection of surface water is also important to ensure protection of the aquifer because of its important contribution to

COMMON SOIL SEQUENCE ALONG THE CLARK FORK RIVER

Missoula County, Montana

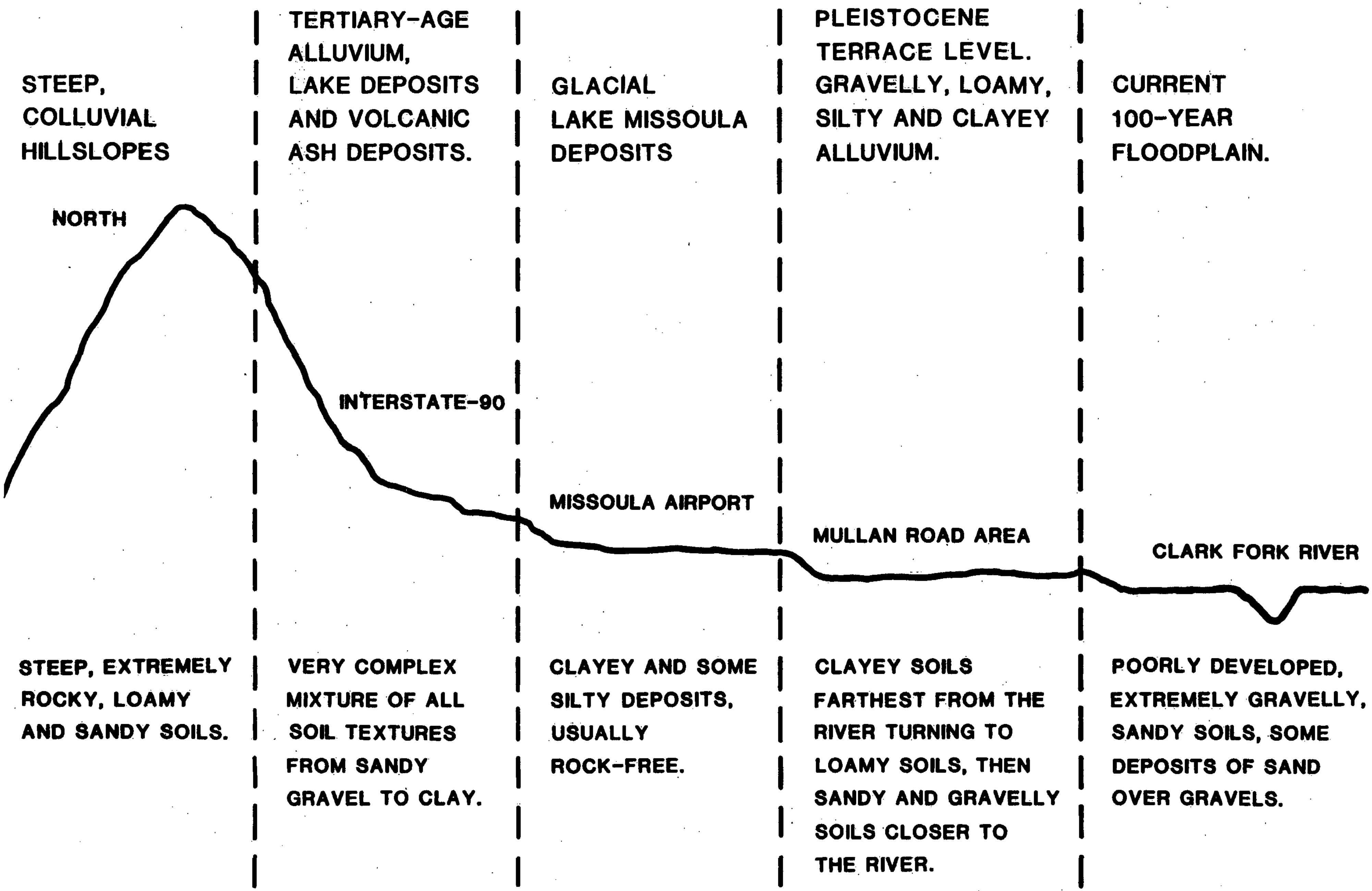


FIGURE 4

the aquifer's recharge. Because the Clark Fork River recharges the Missoula Aquifer, discharges into the river from municipal sewage treatment works, mining operations, and other upstream sources could indirectly contaminate the aquifer.

Potential sources of direct contamination include: septic systems, industrial waste ponds, several historical and one active municipal waste landfill, underground fuel and chemical storage tanks, and high pressure petroleum pipelines. Two major transportation routes, the Burlington Northern Railroad and Interstate 90 run parallel to each other bisecting the northern boundary of the aquifer. Hazardous materials and waste are routinely transported through Missoula over these routes. Accidental spills and releases of these materials could result in catastrophic damage to the aquifer. A number of incidents that have occurred and threatened or contaminated the Missoula Aquifer are described below.

Yellowstone Pipeline

On June 26, 1982, a rupture occurred in a high pressure gasoline pipeline which spewed an undetermined amount of gasoline into La Valle creek located in the north central portion of the aquifer. This spill caused contamination of wells in the aquifer adjacent to the creek. This was the second such rupture of this pipeline that the MCCHD is aware of. There was a leak in the mid 1970s that caused contamination of wells in the Grant Creek area just east of the La Valle Creek drainage.

Milltown Arsenic Contamination

Just east of the proposed designation area is the Milltown Superfund site. The aquifer in this area is contaminated with arsenic and other heavy metals. The source of this contamination is the sediments trapped behind the Milltown Dam located on the Clark Fork River.

Missoula County Weed Control Contamination

In December of 1984 low levels of pesticides were noted in a community water supply serving a KOA campground and mobile home court. Chemical analysis showed that a number of wells had elevated levels of the herbicide, Picloram. Further investigation revealed that the source of the Picloram was the County Weed Control Department which was disposing of unused spray into a sump at their shop located on North Reserve Street.

Browning Ferris Landfill Leachate

The Browning-Ferris Landfill, Missoula's only municipal waste landfill, is located near the northeastern boundary of the Missoula Aquifer between the Grant Creek and Rattlesnake Creek drainages (see Figure 2 - page 7).

In the spring of 1986 routine groundwater samples began showing elevated levels for almost every parameter sampled. Follow-up samples in the summer of 1986 taken from the base of the landfill showed continuing contamination of the groundwater system just down-gradient from the landfill.

Monitoring wells were drilled in the Missoula Aquifer downgradient from the landfill monitoring wells in late 1986. Sampling during 1987 has shown the continued presence of leachate at the landfill, but wells finished in the Missoula Aquifer have not yet shown any contamination. It is hypothesized that the Missoula Aquifer provides a tremendous dilution factor for the landfill leachate and therefore water quality has not changed noticeably in the aquifer. Continued monitoring and assessment are ongoing.

Burlington Northern Diesel Contamination

In the fall of 1986 the Montana Water Quality Bureau (WQB) informed MCCHD that diesel fuel had been detected at the Burlington Northern (BN) Railroad refueling site, located in the northern part of the city of Missoula and entirely within the aquifer boundaries.

The amount of fuel that had leaked into the aquifer was unknown at that time and remains unknown today, but several monitoring wells showed free product on the water table. At least one well had a lens of diesel fuel seven feet thick floating on top of the water table.

Since fall of 1986, BN has attempted to identify the source of the product and begin recovery operations. As of October, 1987 the source of the problem has not been identified and full scale recovery has not been implemented. BN is continuing to work on the problem under the guidance of the WQB.

High Nitrate Levels in the Linda Vista Area

In a subdivision located on the southeast boundary of the designation area at the mouth of Miller Creek, MCCHD discovered that a number of individual wells had elevated nitrate levels. Nine wells in this subdivision had nitrate levels above 10 mg/liter. These levels have been associated with the high use of dry wells (seepage pits) for sewage disposal in this area. These systems are being upgraded upon replacement.

Bacterial Contamination in the Frenchtown Area

In September of 1986, MCCHD became aware that 25 of 36 individual wells, located in a two square mile area near the west end of the designated area, were contaminated with coliform bacteria. Although a definite cause has not been determined, it appears that the bacterial contamination is related to high groundwater during the summer and fall created by recharge from a large irrigation canal. Contamination of the supplies also seems to be correlated with improper well construction.

California Street Gasoline Contamination

Groundwater beneath the California Street area of Missoula was contaminated by gasoline that leaked from a tank buried at the Champion Missoula Sawmill (CMS). Gasoline was detected in domestic wells near the CMS in May of 1985. CMS excavated a 1,000 gallon gasoline tank and discovered many holes in the tank. A loss of 600 gallons of fuel was recorded over a three day period after the tank was pressure tested. The total amount of fuel lost is unknown but it is assumed the tank had been leaking for several years. Champion initiated a groundwater monitoring program in May of 1985 to comply with a request from the Department of Health and Environmental Sciences to determine the extent of pollution. Drinking water and in-line carbon filters for 24 individual wells were provided to the affected neighbors. In January, 1986, when gasoline constituents were verified in samples of the area wells, Champion began a well replacement program for the users. In the process of review for other possible contributors to contamination in the area, an abandoned oil refinery was discovered. This site was tested by an EPA FIT Team and is currently listed as a potential Superfund site.

Storm Water

Urban storm runoff is a matter of interest as a source of groundwater and surface water recharge, but most importantly as a potential source of contamination. According to a recent study by the University of Montana (Woessner/Wogsland, 1987), there are 2669 dry wells in the municipal area that meet the E.P.A. Class 5 description of an injection well. It is estimated that annually, 119 million gallons of contaminant-laden storm water are injected eight to twenty feet deep into highly permeable soils via these sumps. Although the contribution to groundwater recharge is relatively small compared to other sources, the potential for contamination is disproportionately higher. Runoff quality is variable, with annual total dissolved solids levels estimated at more than 4400 tons.

Although it appears most of the chemicals are attenuated within the vadose zone, higher levels of calcium, magnesium, sodium, chloride, and iron have been found in groundwater associated with runoff recharge. Through a 208-sponsored study of Spokane, Washington's groundwater quality, it was estimated that 30% of the contaminant load in residential areas is from storm runoff (Miller, 1979), and this contamination was generally associated with the first 1/2 inch of precipitation. In other research under the National Urban Runoff Projects (NURP), runoff has frequently been seen exceeding water quality criteria for heavy metals such as copper, lead, and zinc.

The above examples of real and potential contamination clearly illustrate the vulnerability of the Missoula Aquifer.

D. Water Quality of the Missoula Aquifer

This section provides information about the chemical and bacteriological quality of the groundwater. Information was obtained from a number of data sources and groundwater studies.

"The Missoula Valley is endowed with a high quality water supply in its groundwater aquifer." This was how the Missoula Valley Water Study (MVWS)(Juday and Keller, 1979) summarized the groundwater serving the Missoula Valley in 1978. The quality of the Missoula Aquifer is considered to be very good with respect to established drinking water standards. The water quality of the aquifer is related to, and dependent upon, the recharge sources and the existing and potential contamination sources. The MVWS, which serves as a baseline for water quality data, presented a number of questions that needed to be investigated and answered and was designed to serve as a "point of departure" for local government to carry on future studies.

Of several hundred wells sampled during the MVWS study, only 3 showed nitrate levels that approached or exceeded 10 ppm. Most of the wells showing elevated nitrate levels were found outside the designation area, except for some wells located in the lower Rattlesnake drainage. These levels are assumed to be at least partially related to large numbers of seepage pits (dry wells) located in this drainage. City sewer is presently being constructed to service the Rattlesnake area and should help alleviate a portion of this problem.

The groundwater of the valley is considered relatively hard as expressed by the sum of calcium and magnesium ion concentrations. The hardness of the water causes some complaints of scaling, but water softeners are not usually recommended or widely used. Water from the municipal water supply shows a hardness ranging from 138 to 210. The groundwater is a calcium-bicarbonate-type water and has total dissolved solids (TDS) usually less than 350 milligrams per liter (mg/l). Chloride ion concentrations are less than 10 mg/l and sulfate is less than 30 mg/l. The pH ranges from 6.8 to 8.5. Geldon (1979) reports calcium:silica ratios in the Missoula aquifer averaging 2.3. This implies a relatively rapid circulation of groundwater through the aquifer. The ratio decreases southwestwardly with distance from the Clark Fork river. Seasonally, wells near the Clark Fork near downtown Missoula show 60% fluctuations in TDS which also reflect the TDS changes in the Clark Fork river (Hydrometrics, 1984).

Water found in the tertiary sediment hydrostratigraphic unit is also considered a calcium-bicarbonate type of water with TDS generally less than 500 mg/l (Geldon, 1979; Juday and Keller, 1979). Iron concentrations typically exceed the 0.30 mg/l drinking water standard. In an attempt to describe the circulation time of groundwater in the Tertiary sediments, Geldon used calcium:silica ratios and found they averaged 0.64 for this groundwater and concluded that the water took a longer time to circulate through the system than the groundwater found near the Clark Fork river.

Recent chemical data obtained from 1984-1986 are shown in Figures 5 - 7. This data was obtained from Mountain Water Company, owner of the municipal water utility, and the Missoula Aquifer Study being conducted in cooperation between the MCCHD and the University of Montana. Results of MWC data and the Missoula Aquifer study show no violation of the maximum contaminant levels established for the State of Montana primary drinking water standards. Small community water supplies are also sampled once every 5 years for chemical constituents. Data from the approximately 33 community water supplies in the valley show no

MISSOULA VALLEY AQUIFER WATER QUALITY

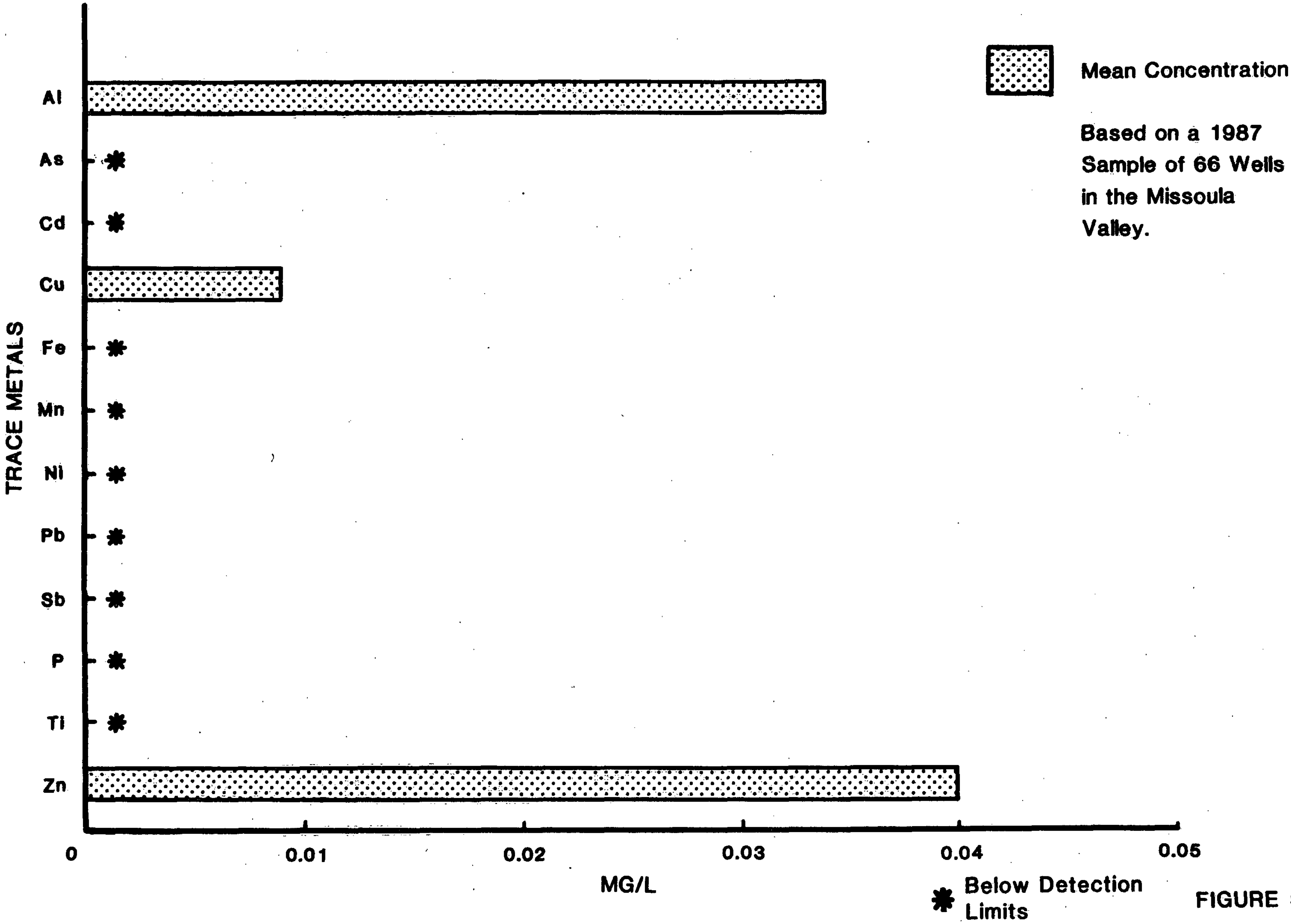


FIGURE 5

MISSOULA VALLEY AQUIFER WATER QUALITY

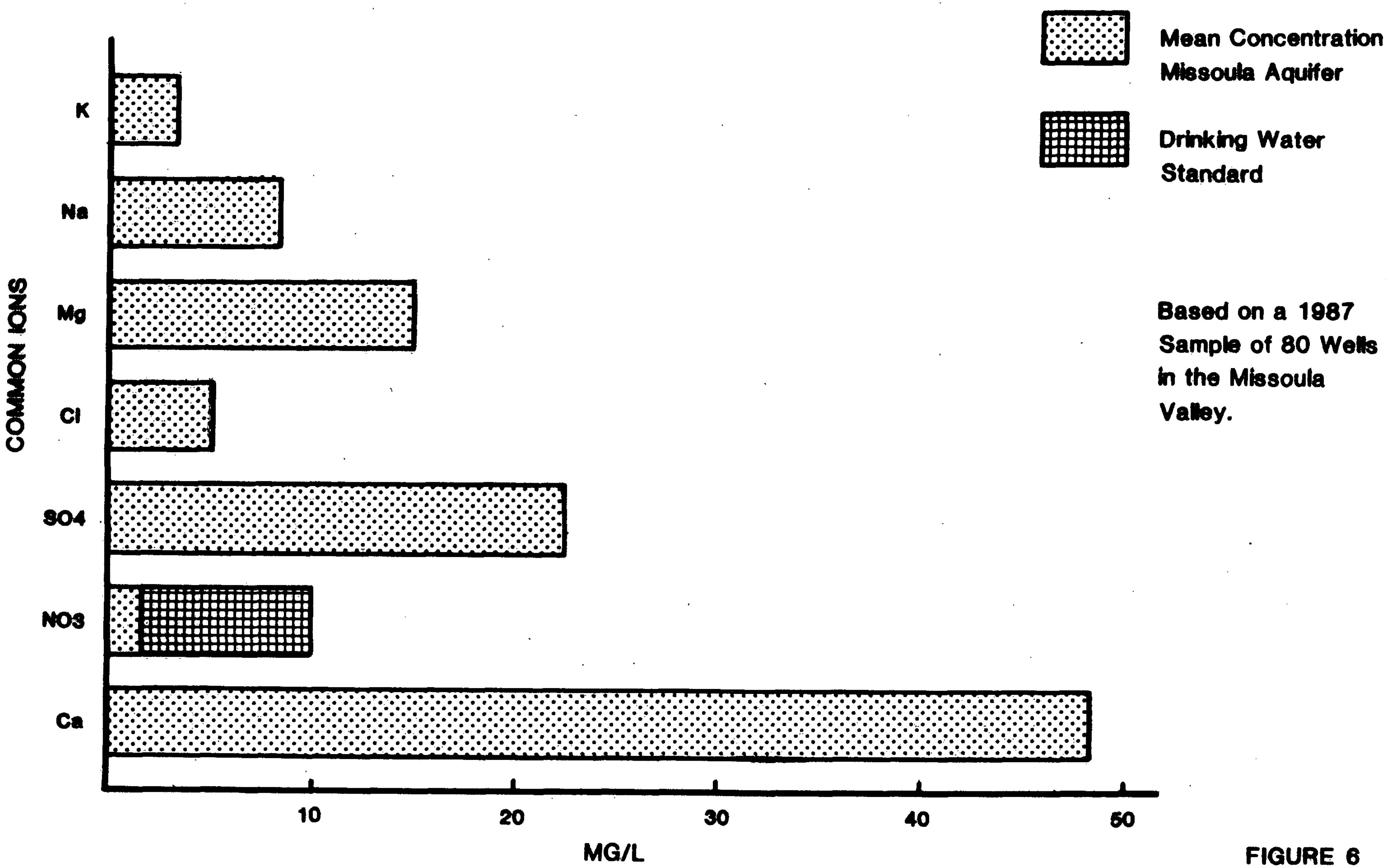


FIGURE 6

MISSOULA VALLEY AQUIFER
Municipal Water Quality

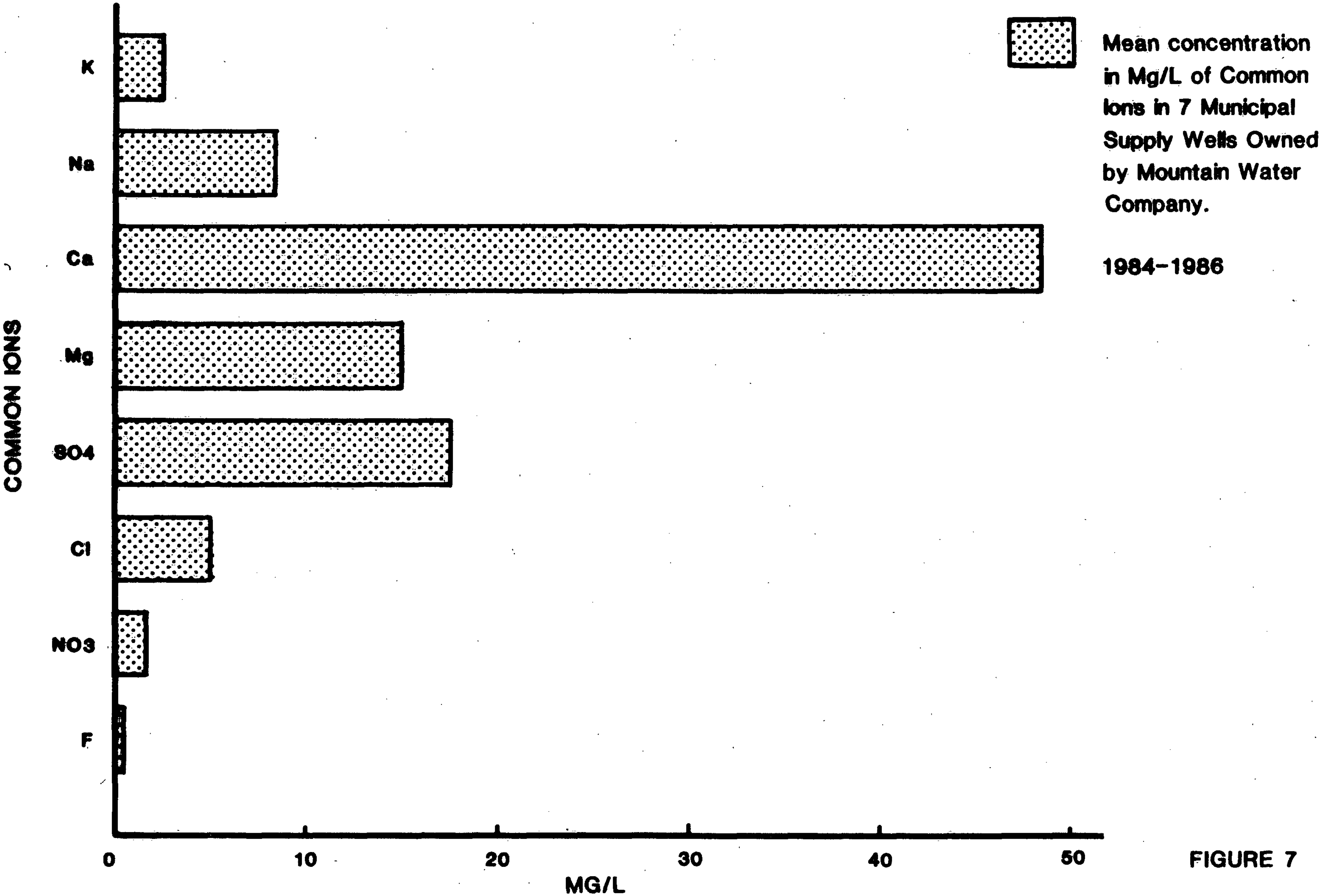


FIGURE 7

violations of the Montana primary or secondary drinking water standards. The chemical analysis results for the community supplies located within the designated area are included in Appendix A.

The bacterial water quality of the aquifer is more difficult to determine because of the problems associated with well construction. Montana has only recently adopted well construction standards, and many water samples that show bacterial contamination problems are from shallow wells or wells which are not properly constructed.

The Missoula Valley Water Study found that a high percentage (25%) of 104 wells being sampled monthly for coliform bacteria showed contamination in one or more samples during the study period (approximately one year). The study attributed contamination problems to the proximity of most of the contaminated wells to either the Clark Fork or Bitterroot rivers, and to the depth of wells. The contamination problems peaked in July and early August and it was surmised that coliform bacteria previously static in the soil were mobilized by rising groundwater and were introduced into the aquifer. Bacterial samples collected from 65 wells in conjunction with the Missoula Valley Aquifer Study revealed that 23 percent were contaminated with coliform bacteria.

Mountain Water Company also monitors bacterial water quality in the valley and collects 54 bacteriological samples each month. These samples show almost no contamination.

E. Relationship of Water Purveyor to Petitioner

Drinking water in the Missoula valley is solely groundwater and comes from public or individual wells. Municipal water is derived from two local water utilities, Mountain Water Company (MWC) and Clark Fork Water Company (CFWC), which distribute water from wells tapping the Missoula Aquifer to residents in the Missoula city limits or its urban fringe area. Individual wells and small community water systems represent the second category defined as an individual user of groundwater.

Both of these sources are regulated by the MCCHD and other State and Federal agencies which are responsible for the maintenance of both surface and groundwater quality. The MCCHD has further responsibility for the regulation of sewer and septic systems throughout the valley and the remainder of Missoula County.

III. CHARACTERISTICS OF THE AQUIFER SERVICE AREA

Executive Summary

The Missoula Aquifer serves users within its boundaries, and also provides water to several residential developments along hillsides beyond the Aquifer boundaries. An estimated 65,000 of Missoula County's 77,400 residents use water from the Missoula Aquifer. Of those 65,000, about 47,000 people receive water from privately owned water utilities and the remainder receive water from individual wells or small community water systems.

The Mountain Water Company supplies water to nearly 45,000 residents in and around the City of Missoula. Mountain Water operates 34 supply wells in the Missoula urban area as their only source of water. All of these wells are finished in the Missoula Aquifer.

Residential water consumption ranges from about 525 gallons per day (gpd) to 700 gpd. Commercial/Industrial water consumption averages about 1660 gpd. Mountain Water Company estimates that 51% of water production is lost to leakage in the distribution system.

Stone Container Corporation owns and operates a pulp mill West of Missoula that is the single largest user of Missoula Aquifer water with an average daily production of 24.5 million gallons per day.

A. Aquifer Service Area Boundary

Water from the Missoula Aquifer serves users within its boundaries but also includes a few residential developments along the hill slopes outside of the boundaries. These developments include three areas served by a municipal system: Farviews, South Hills, and Ben Hughes Addition. Two have their own community water system: Sorrel Springs and Goodan & Kiel Estates (see Figure 2, page 7). Both Sorrel Springs and Goodan & Kiel Estates have wells tapping the Missoula Aquifer water on the valley bottom which is pumped up slope to the residential developments. Farviews and Ben Hughes Addition are served by MWC's distribution system, while the South Hills area is shared by both MWC's and CFWC's water lines.

B. Population of the Aquifer Service Area

Census data from 1980 show a population of 77,400 in Missoula County. Although the aquifer does not extend over the entire county, the majority of the population lives within the Missoula valley. Census tract data further enables delineation of the aquifer service area's population. Appendix B displays the breakdown of census tracts within the county and an estimated percentage that reside within the service area. Although these figures represent the 1980 population, recent studies have shown little change in the county's population up until 1985 (BBER, 1986). An estimated 65,000 use water from the aquifer. Of that amount, 44,755 are served by MWC's system and 2,329 receive water from CFWC's water distribution lines. The remainder rely upon water from individual wells or from small community water systems. An estimated 150 individuals, residing outside of the aquifer boundaries but within the service area, rely upon older sediments (Tertiary sediments/Renova Equivalent) for their water supply.

C. Mountain Water Company's System

Mountain Water Company (MWC) operates the main water utility in the Missoula valley, providing water to nearly 45,000 residents. In 1986, MWC's total customer accounts numbered 16,331 with approximately 1300 of those being commercial/industrial accounts. MWC operates 34 wells in the Missoula urban area as their source for water production. All of MWC's wells produce water from the Missoula Aquifer, with the most productive wells situated near the Clark Fork River. The MWC system includes 18 storage tanks, with three of these having a capacity of one million gallons or more. The distribution system consists of nearly 170 miles of water mains. Approximately 2% of the mains are old, wooden stave pipes installed during the early years of the water distribution system. The distribution lines reach residents of the city of Missoula and the area immediately outside the city limits (see Figure 8).

Eight percent of MWC's customers are commercial/industrial and the remaining are domestic users. Only about one-third of residential customer water consumption is metered, whereas all commercial/industrial water consumption is metered. A 1981 study performed by MWC demonstrated that residential water consumption varies from metered to unmetered customers. Metered customers use between 0.35 to 0.37 gpm (504-533 gpd), whereas unmetered residences range from 0.39 to 0.51 gpm (562-734 gpd) (MWC,1981). Variations appear dependent upon fluctuating climatic conditions. However, data for 1986 show residential use to be slightly higher than average even though precipitation was higher than normal. Combined metered and unmetered residential customers averaged 0.49 gpm (703 gpd). Commercial and industrial users averaged 1.15 gpm or 1659 gpd for 1986 (see Appendix C).

These values are much lower than the total water produced for the system because they fail to take into account leakages in the distribution system. MWC's Control of Water Production study of 1981 demonstrated leakage from their system is approximately 51% of production (MWC, 1981). Although leakage in a system supplied by groundwater would most likely return to the aquifer, examining the replaceability of the source must include leakage

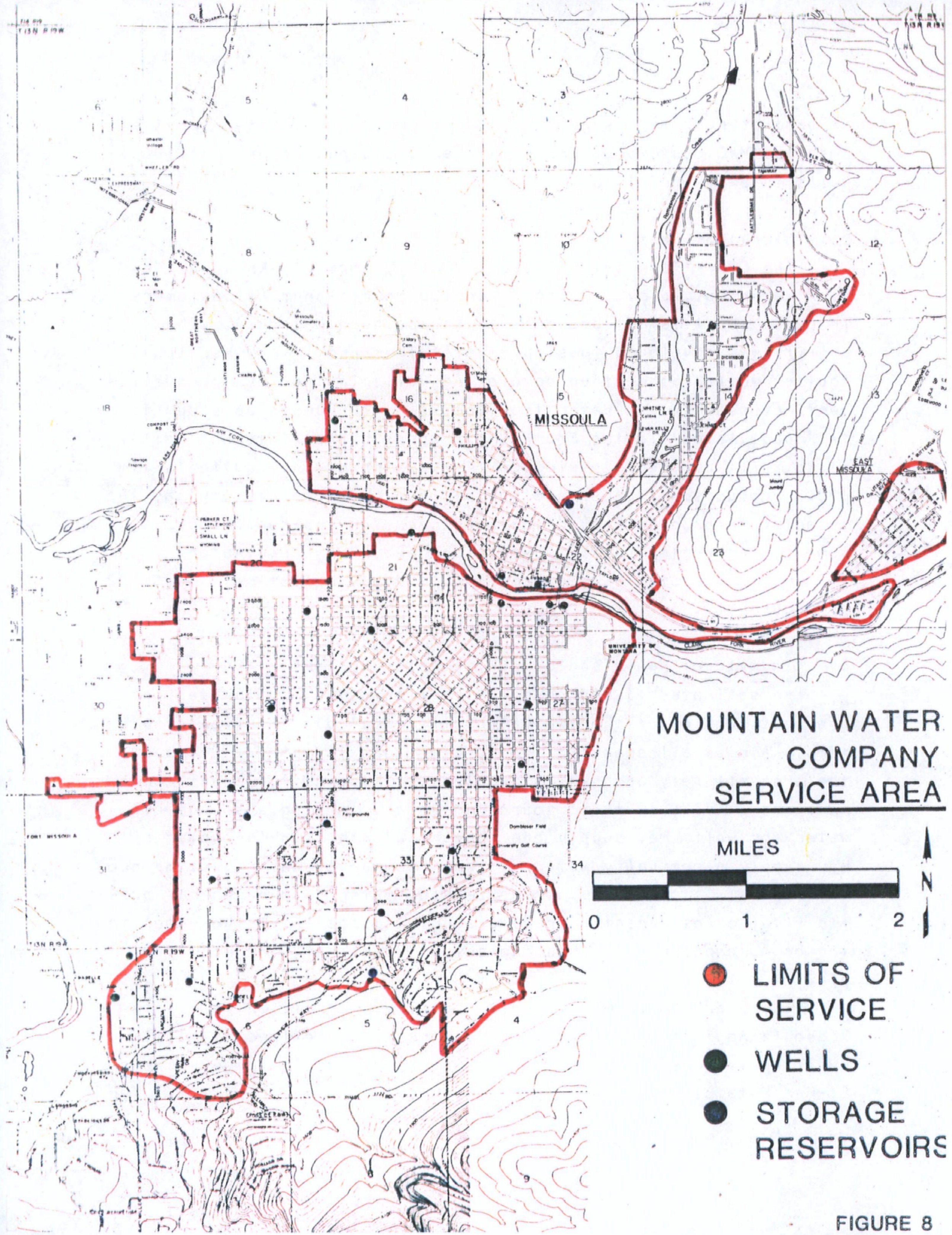

MOUNTAIN WATER COMPANY SERVICE AREA
MILES
0
1
2
N
LIMITS OF SERVICE
WELLS
STORAGE RESERVOIRS
MISSOULA
EAST MISSOULA
UNIVERSITY OF MONTANA
CLARK FORK RIVER
FORT MISSOULA
County Fairgrounds
Dornblaser Field
University Golf Course
T13N R19W

FIGURE 8

as part of customer usage. Actual usage in the aquifer service area for MWC customers, CFWC customers, and people on individual wells is explained in Section IV B.

D. Clark Fork Water Company's System

The Clark Fork Water Company (CFWC), formerly known as Western Water Co., provides water service to residential customers in newer subdivision developments in southern Missoula. The utility was developed to supply water from prolific Missoula Aquifer wells rather than developing wells in the less productive Tertiary sediments. Water from the wells is pumped up slope to two subdivisions in the South Hills area: Linda Vista and Valley Vista. All of CFWC's customers lie outside of the aquifer's limits. Production figures are unavailable, but the utility has the capacity to produce 5 mgpd to serve over 740 residential customers. An estimated 2329 people are served by CFWC water.

Customers of CFWC are unmetered and pay a flat rate of $9.90 per household.

E. Individual Wells and Community Water Systems

An estimated 13,000 people live within the aquifer service area but outside of the two water utilities' distribution systems. Almost all domestic, commercial, and industrial users in the area all rely upon wells tapping the Miocene to Recent coarse sand and gravels as their source of water. A single source of water (or well) may supply one household with drinking water or may supply a community water system. Community water systems are defined as: 1) a private hookup serving water to the general public (i.e. a restaurant), or 2) a single source providing water to ten or more hookups (or households) and serving 25 or more people.

There are 60 community water supplies identified within the Missoula Aquifer boundary and 33 of those are defined as multi-dwelling systems. Some of these systems are quite large such as El-Mar Estates which has nearly 500 hookups in their system. Two community systems, Goodan and Kiel Estates and Sorrel Springs, lie outside of the aquifer's boundaries yet draw their water from wells within the boundary and from Missoula Aquifer sediments. Development of wells in the Missoula Aquifer which pump water up to the subdivisions have proven to be more feasible than developing groundwater from the less productive sediments at the subdivision site.

F. Stone Container Corporation's Industrial System

The Stone Container pulp mill west of the city of Missoula represents the largest single user of Missoula Aquifer water producing nearly as much water as MWC supplies to its 16,000 customers. The mill pumps 24.5 million gallons per day (mgpd) from 12 wells along the Clark Fork River (MDHES, 1985). The water is used primarily for industrial needs and is not required to be of drinking water quality. For purposes of replacement, the pulp mill's use will not be considered as part of the aquifer's drinking water supply.

IV. CURRENT DRINKING WATER SOURCES AND USES

Executive Summary

Although other sources of drinking water, such as Rattlesnake Creek, have been used in the Missoula Valley in the past, no source other than groundwater has been used since 1983.

Average daily consumption of water in the Mountain Water Co. system is about 550 gallons per day including leakage from distribution pipes. Average daily use excluding leakage is estimated to be about 270 gpd. Total drinking water use in the Missoula Aquifer service area is estimated to be 30 million gallons per day (mgpd).

Water use fluctuates very little from October to March averaging about 630 million gallons per month. Consumption increases in April and continues to rise during the summer months due to lawn and garden sprinkling. Water consumption peaks in August when daily water demand can exceed 50 mgpd. Annual and seasonal demand can vary drastically depending on climatic conditions.

Wells tapping the Missoula Aquifer sustain very high yields. Mountain Water Company wells produce an average of over 1000 gallons per minute (gpm) with some individual wells producing up to 7,000 gpm. Currently, the only limit on Missoula Aquifer production is demand for water.

A. Current and Past Drinking Water Sources

The Missoula Aquifer provides nearly all the drinking water to residents of the service area. As outlined previously, groundwater from the Missoula Aquifer is distributed from a variety of sources. Only a very small percentage (<0.3%) of service area residents use another source for drinking water (Tertiary sediments/Renova Equivalent) (see Table 1).

Prior to July of 1983, MWC and the Missoula urban area used surface water from Rattlesnake Creek. This source had been in use since 1875 until an outbreak of Giardia lamblia forced the closure of the system. The existing treatment processes lacked the capability to filter the Giardia cysts, cutting off approximately 45% of MWC's total water production. Facing high summer water demands, the utility had to increase well production to offset the loss from the surface water source.

To resume diversions of the Rattlesnake Creek, the system would require additional treatment processes to adequately filter the Giardia cysts and to meet existing surface water quality standards. The construction of a more elaborate treatment system has not been pursued by MWC because of the costs involved in the development and operation of a plant. The options and costs for reestablishing Rattlesnake Creek into MWC's system are further explained in Section V. Without these improvements MWC must rely upon well water for supplying the Missoula urban area with a drinking water supply.

No other source of water other than groundwater has been used in the Missoula valley for drinking water since 1983.

TABLE 1

CURRENT DRINKING WATER SOURCES IN THE AQUIFER SERVICE AREA

Use	Public Supply MWC	Public Supply CFWC	Private Supply	Total
Source				
Missoula Aquifer	83.1%	2.8%	13.8%	99.7%
Rattlesnake	0.0%	0.0%	0.0%	0.0%
Other Aquifers	0.0%	0.0%	0.3%	0.3%
Totals	83.1%	2.8%	14.1%	100.0%

* See Appendix C for methods for developing water usage for each source

B. Water Usage

Daily drinking water use from the Missoula Aquifer was estimated from MWC's record of water production (Appendix C) from 1976 through 1986. These values represent water produced from the aquifer (and Rattlesnake Creek while in production) and distributed in their water mains to residential and commercial customers. While this accounts for only 75% of the service area population, it portrays a fair representation of individual use throughout the valley.

For the last ten years MWC has annually produced an average of nine billion gallons from both ground and surface water sources. About 45,000 people live within MWC's service area equalling a daily use of 550 gallons of drinking water per person (residential, commercial, and industrial uses). This value appears high for two reasons. One, customer use is dependent upon demand rather than availability. Missoula area water users have not had to face water rationing and conservation measures during sustained dry periods or droughts. Use is at its highest during extremely hot and dry summer months as residents increase their lawn and garden watering. The second reason is the high leakage rates from MWC's old water distribution system. It is estimated that the current system leaks as much as 55% and average 51% of the total water produced.

If leakage could be eliminated, the base daily per capita use would be 270 gallons. However, leakage appears to be unavoidable in the current distribution system and even the best system exhibits some loss. Water use by the residents outside of MWC's system is assumed to be similar but will exhibit much lower leakage rates in their distribution lines. Leakage in Clark Fork Water Co.'s lines is expected to be about 25% of total production. Water use in CFWC's service area is approximately 360 gallons/person/day.

Small community water systems and individual wells have little or no leakage due to limited distribution lines. However, if their groundwater supply required replacement, service lines would be required to distribute water from an auxiliary source. It is estimated that leakage would be 15% of the total water produced. Assuming base water use to be similar to MWC customers, the actual daily per capita use is 317 gallons.

Total daily use averaged annually is displayed in Table 2. Drinking water use is estimated to be 30 million gallons per day for the Missoula Aquifer service area.

TABLE 2

WATER USE FROM THE MISSOULA AQUIFER

	Production (MGPY)	Population	Daily Use* Per Capita (GALLONS)	Daily Use* Total (MGPD)
MWC	8991.85	44,755	550	24.63
CFWC	--	2,329	360	0.84
Individual	--	13,198	317	4.19
Frenchtown Mill	8942.50	--	--	24.50
		Total Withdrawal (All Uses)		54.16
		Withdrawal (Drinking Water)		29.66

* See Appendix C for methods used in estimating water use

C. Seasonal Use and Variations

Monthly use from October to March fluctuates very little and averages about 630 million gallons/month, but beginning in April water consumption begins to increase (see Figure 9). The increase is primarily attributable to increased lawn and garden sprinkling, with use peaking in July and August. Within MWC's system, daily production can top 40 million gallons. Annual and seasonal production may vary dramatically depending upon summer climatic conditions. Annual production may vary as much as two billion gallons in consecutive years due to variable climatic conditions Appendix C).

Gerald Lukasick, an engineer for MWC, reported that daily peak use has reached 46 million gallons within their system. Since MWC customers only account for three-quarters of the service area population, total production valley-wide could reach 60 million gallons in a single peak use day. In reviewing the replacement of the existing system, estimated peak usage in the Missoula Aquifer service area is 50 million gallons in a single day.

D. Production Potential and Limitations

Actual production potential of the Missoula Aquifer and recharge and discharge volumes to the groundwater system are currently being studied. A further discussion of recharge/discharge relationships is in Section X, Aquifer Recharge and Discharge. Production within MWC's system and generally throughout the aquifer service area has been governed by customer demand. The development of the groundwater supply rather than a surface water source has typically offset the demand.

The wells tapping the Missoula Aquifer sustain very high yields. Within MWC's system an average well produces 1000 gpm, many produce over 3000 gpm, and the most prolific well within the system can pump from 6500-7000 gpm operating on the average 17 hours per day. Recent aquifer testing show that these wells exhibit slight drawdown and rebound quickly to static water level

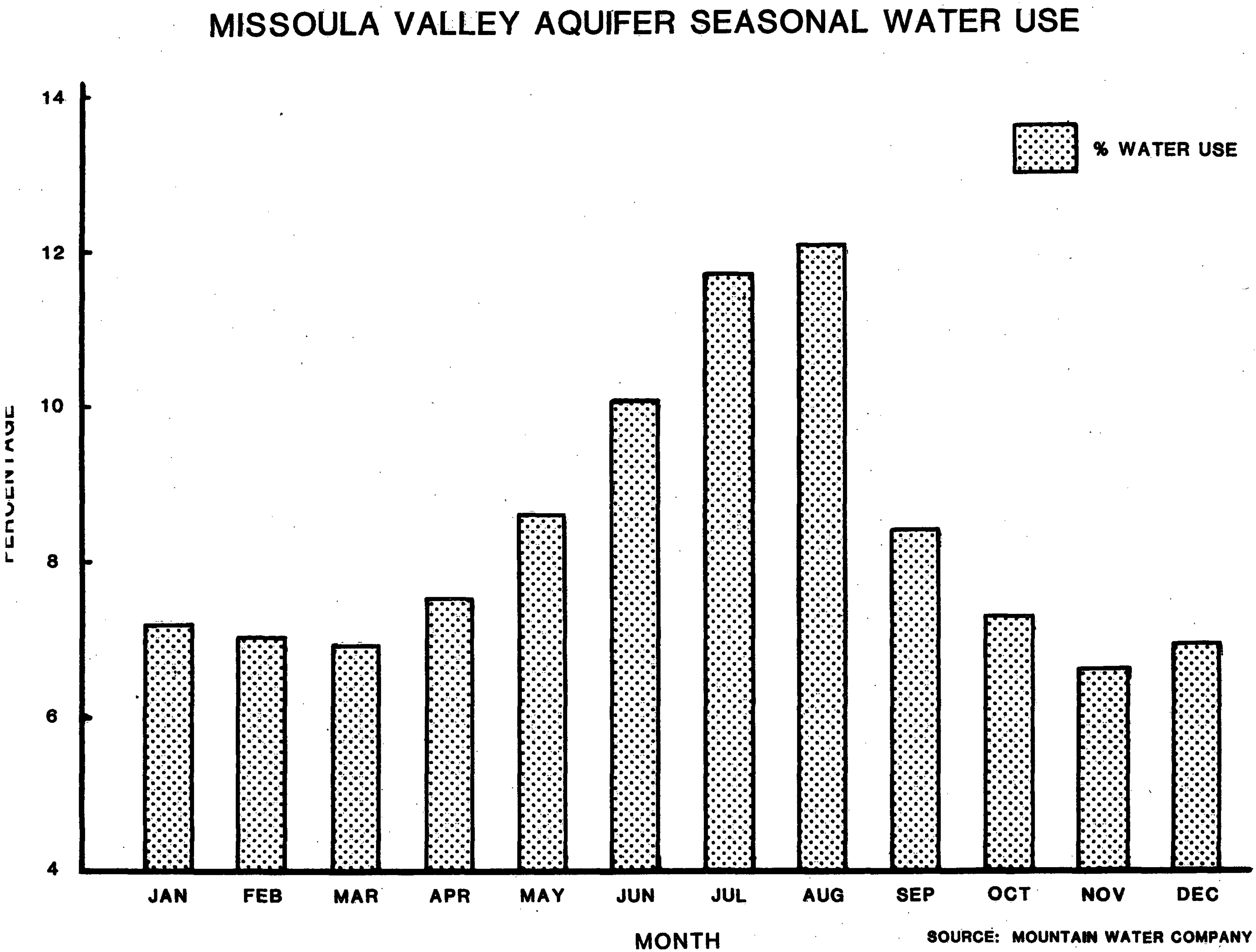

MISSOULA VALLEY AQUIFER SEASONAL WATER USE
% WATER USE
PERCENTAGE
14
12
10
8
6
4
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH
SOURCE: MOUNTAIN WATER COMPANY

FIGURE 9

conditions (Clark, 1986). Many of the large production wells used by MWC are in close proximity to the Clark Fork River and are receiving direct recharge from the river. The potential of the aquifer in other areas of the basin are similar and is discussed further in Section VIII D, Groundwater Hydrology.

Further production and development of the Rattlesnake system has been set aside due to poor water quality related to *Giardia* and the costs of providing effective treatment of the surface water. Prior to contamination, the Rattlesnake provided 45% of MWC's water supply or roughly 11 million gpd. The Rattlesnake watershed is north of the city of Missoula and includes the Rattlesnake Recreation and Wilderness areas. The watershed is closed to motorized traffic but remains open to other public recreational uses such as hiking, hunting, and fishing. The water system includes an intake dam located 2.1 miles north of the city limits and two 30" water mains that feed a storage tank at Waterworks Hill. From the Waterworks storage reservoir, the system was capable of supplying water to much of the city with minimal pumping expenditures.

Volume of water available from Rattlesnake Creek will vary depending on the type of treatment required for providing drinking water. Sanderson, Stewart, and Gaston Engineering prepared a study examining the costs of providing different forms of treatment to the Rattlesnake. They used plant designs with a daily capacity of 10 mgpd. This appears to be the optimum size for a full scale conventional treatment plant on Rattlesnake Creek.

Water quality in the creek remains good despite the *Giardia* contamination. Prior to 1983, the system only required sedimentation and chlorination for treatment. There were periods of the year in which Rattlesnake water was untreatable: during high runoff when turbidity could not be controlled by sedimentation, and very cold periods in the winter when water temperatures approached the freezing point and the danger of frozen pipes existed. Improving the treatment facility would reduce these problems and create a more reliable water supply. However, reintroducing

Rattlesnake Creek water into the water system would require either expensive filtration treatment or its equivalent, to remove the *Giardia*. These alternatives are discussed later as potential sources.

V. CONSTRAINTS AFFECTING WATER DEVELOPMENT

Executive Summary

Western Montana generally has an abundant surface water supply, although some localized water shortages occur in the dry summer months of drought years. In the Missoula Valley water rights to almost all of the surface water in local streams has been allocated to agricultural and hydropower users.

The 1973 Montana Water Use Act establishes a central system for the acquisition, administration and determination of all water rights in Montana. Montana law requires potential users of water to apply for permits for both surface water and groundwater. The Montana Department of Natural Resources and Conservation (MDNRC) is responsible for the permitting of water rights. Applicants are granted rights if their intended use does not impact water use by those with prior rights. Despite a process to determine new water rights, the water of many local streams is severely overallocated.

Potential alternative drinking water sources were evaluated to determine whether water is legally available through allocation. A source was determined to be administratively feasible if water rights could be obtained. Because the MDNRC has placed a temporary closure in the Missoula Valley to all new ground and surface water sources, only current water supplies were evaluated.

Alternative sources that were determined to be administratively feasible include: Rattlesnake Creek, Bitterroot River, Clark Fork River, O'Brien Creek and deeper Missoula Valley Aquifers.

Water quality classification in the Missoula Valley include A-1 Closed (drinkable with simple disinfection) for Rattlesnake Creek above the current dam, and B-1 (drinkable with conventional treatment) for the Clark Fork and its tributaries.

Introduction

Western Montana generally has abundant water flowing in the streams and rivers draining the snowfields of the nearby mountain ranges. Most rivers and many of the large streams maintain flow throughout the year, but some become appreciably low in the late summer when snow melt has disappeared and recharge from groundwater diminishes. However, much of this surface water supply is already allocated to agricultural and hydropower users throughout the valley, and holders of junior water rights often lack water in the late summer months. A river such as the Clark Fork, may discharge billions of gallons daily under a bridge, but may be completely confined by institutional constraints that prevent the diversion of a single gallon of water.

This section will explain the constraints confronting the accessibility and availability of water in western Montana. The section will demonstrate the legal obstacles in obtaining water rights and discuss the limitations related to water quality and water treatment.

A. Montana Water Law

The water rights issue in Montana dates back to early mining operations of the 19th century when water was the dependent variable for success. With agriculture following in the shadow of mining operations, the water use issues gained even more legal significance and prominence. Authority for historical water use and for their ditch systems is generally unquestioned. "First in time, first in right" applies in Montana water rights issues.

Prior to 1973, no exclusive method of water right appropriation existed. The most common method for acquiring water rights consisted of making a diversion, posting a notice of the diversion, and then filing with the County Clerk and Recorder's office. The appropriation of groundwater was legalized by the 1962 Montana Groundwater Law. It established for the first time a formal procedure for obtaining groundwater rights. The historical groundwater rights established through use were assumed to be valid from that time forward.

The 1973 Montana Water Use Act established a uniform central system for acquisition, administration, and determination of all water rights. It created a centralized record system and a single, exclusive system for establishing water rights by a permit system. It also mandated the adjudication of all existing rights. There is a requirement for the appropriator to file for a permit with the Montana Department of Natural Resources (MDNRC) to obtain a new water right if it involves either the construction of a new surface water diversion or impoundment or a water well with an anticipated beneficial use of more than 100 gallons per minute.

Montana water law requires potential users to apply for permits for both groundwater and surface waters. Applicants are granted rights if their intended usage does not impact water use by those with prior or senior rights to the applicant. If it is demonstrated that the applicant's withdrawal of water will impair another's use, the permit may be disallowed.

One extremely important provision of the 1973 Montana Water Use Act allows public entities to reserve previously unallocated water for existing or future beneficial uses. Reasons for reserving water may be for consumption or to maintain a minimum flow, level, or quality of water. Agencies must prepare an application to the MDNRC and provide the following information:

1. The purpose of the reservation, including the beneficial uses intended.

2. The need for the reservation and why a water right by permit will not meet the needs.

3. If consumptive use is involved, why the necessary facilities cannot be build to divert, convey, and use the water in the near future, and how that situation may change.

4. If the application is for instream use, such as fish, wildlife, recreation, water quality, or protection of existing rights, the application must document why the requested flow or level should be protected. It must also describe the environmental benefits and costs of maintaining or not maintaining the flow or level requested.

5. The amount of water necessary for the purpose.

6. A showing that the reservation is in the public interest, documenting any benefits which will occur, and including consideration of both economic and environmental factors.

This reservation process is the key to future surface and groundwater development.

Montana Senate Bill 76, enacted in 1979, further defined the purpose of water rights protection. "An Act to Adjudicate Claims of Existing Water Rights in Montana" provides for four water judges to be appointed to study and adjudicate all water rights by 1992. When this occurs, the state and its water users will for the first time, have a record of all water rights including those pre-1973 claims.

Familiarity with water availability problems is essential to understanding water rights problems in Montana. In the spring of the year Western Montana generally has abundant water flowing in the streams and in underground reserves collected from nearby mountain ranges. Most rivers and many of the larger streams maintain flow throughout the year, but some do become appreciably low in the late summer. Since the climate is rated as arid (an average of 13 inches/year), it is understandable that late season water supply can be diminished. Also, this water supply is allocated to agricultural and hydropower users, and holders of junior water rights often lack water in the late summer months. So the availability of water becomes a question of low flow supply. A source of water may be open to permitting or allocation, but that source may not be guaranteed throughout the year because of depleted supplies. Being open to allocation is, therefore, not a guarantee of use. For example, one of the small streams feeding the valley has water allocated to four times its average flow and faces possible closure to further permitting. All streams have the potential for contamination by Giardia or other pathogens. The Bitterroot and Clark Fork Rivers have the capacity to supply municipal water demands, but hydropower users downstream have rights to the entire flow of the rivers. This downstream hydropower reservation, coupled with the limited availability of water from side tributaries such as Rattlesnake Creek, make future development of water sources a problem.

In Missoula, Mountain Water Company is the primary supplier of municipal water. Their water rights include 184,890 acre feet of water, 70,391 acre feet being groundwater reserves and 114,499 acre feet being surface allocation in the Rattlesnake Creek drainage. Although this may appear to be sufficient quantity for the municipality, again the demand may well exceed the availability of that allocation.

For the purposes of this petition, examining the replaceability of the current groundwater supply will also require development of distribution systems for those currently reliant only upon their own wells. Most of the aquifer service area west and north of the Missoula city limits lack the distribution system necessary to provide centralized water service. In determining the practicality of an alternative, these costs must be included in the final analysis. As shown in later sections of this document, the cost of developing distribution lines for these areas far exceeds development of an auxiliary source.

Each administratively feasible alternative is listed in Section VI, Potential Drinking Water Sources. Administratively feasible generally infers water that is available for allocation either by permitting or through the reservation process. Relying upon adjudicated or legislative activity to provide alternative water supplies is considered too prohibitive. Purchase and transference of water rights is also considered too cumbersome because of the notification and approval process of downstream users and additional costs involved in acquiring rights. MDNRC has placed a temporary closure upon the valley to all new ground and surface water permit applicants, thus eliminating all sources except for current water supplies. This action may force state agencies to examine the legal availability of water in the larger basins of Montana. For purposes of simplifying the discussion, we assume the options and scenarios presented below will face few obstacles in obtaining water rights.

Legal Constraints on Alternate Water Sources

Although the Missoula valley has abundant river water, very little water is stored in nearby lakes and reservoirs. The nearest lakes are in the Rattlesnake surface water system but are located within a designated wilderness area. Painted Rocks Reservoir, 90 miles south of Missoula, appears to be the most reliable source of stored water. This reservoir has 32,000 acre feet of storage with approximately 16,000 acre feet allocated to date. 15,000 acre feet are used to maintain instreamflows of the Bitterroot River. A contractual arrangement with the Bureau of Land Management to transfer water rights from the Hungry Horse Dam to the Clark Fork River may also be feasible. Since Washington Water Power is interested in volume flow to their downstream generating plants, a trade for Flathead River storage would not affect their water rights. Development of a reservoir near the Missoula valley remains a possibility and is discussed later in the petition.

Aquifers besides the Missoula Aquifer both within and outside of the Missoula valley may also be considered as alternative sources. Oligocene-Miocene sediments and the fractured Pre-Cambrian bedrock aquifers are used sporadically throughout the valley but tend to yield considerably less than the shallower Missoula Aquifer. The Bitterroot Valley, south of Missoula, may remain as a possibility for development if distribution mains are economically feasible.

Replacing the current groundwater supply, should it become polluted, will also require development of distribution systems for those currently reliant only upon their own wells. Most of the aquifer service area west and north of the city limits lacks mains to provide centralized water service. In determining the practicality of an alternative these costs must be included in the final analysis. As shown in later sections of this document, the cost of developing distribution lines for these areas far exceeds development of an auxiliary source.

Each feasible alternative for replacing water supplies for the aquifer protection area is listed in Section VI. If there are constraints that appear to be binding, those are noted. Otherwise, the alternatives are in the category of constraints unlikely to be binding.

For a government entity there are two options for the allocation of water rights. An application for water rights requires the construction for use of the water be done within a ten (10) year development period. Because of difficulties in predicting future use and costs of construction within a ten year time frame this option for water rights is not popular and would not be recommended for alternate water rights development in Missoula. The second application process is referred to earlier and involves a reservation of water use which is reviewed by the MDNRC every 10 years. The reservation involves no construction requirements, and off-stream storage can still be secured in the future, although users with prior rights such as Washington Water Power Company, may require conditions be added to an approval.

B. Montana State Water Standards

The Montana Clean Water Act provides for the "... classification of all waters in accordance with their present and future most beneficial uses ...", and to "... formulate standards of water purity and classification of water according to its most beneficial uses ..." (MCA 75-5-301). Pursuant to State Law, the surface waters were classified with associated standards in 1972 under the Administrative Rules of Montana.

Montana's stream classification system dictates the degree to which State waters must be treated before they are determined to be suitable for human consumption. Sources of drinking water which do not require extensive filtration and/or chemical treatment have a major advantage over those that can only be developed after the addition of expensive treatment facilities.

In the Missoula Valley area there are two different stream classifications. The Clark Fork River and most of its tributaries are classified "B-1." The Administrative Rules of Montana (ARM) 16.20.618(1) state:

> "Waters classified B-1 are suitable for drinking, culinary and food processing purposes after conventional treatment; bathing, swimming, and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl, and furbearers; and agricultural and industrial water supplies." (See Appendix D)

The Rattlesnake Creek above Mountain Water Company's intake dam is classified A-Closed. ARM 16.20.616(1) provides that:

> "Waters classified A-Closed are suitable for drinking, culinary and food processing purposes after simple disinfection." (see Appendix D)

Thus, the classification of State surface waters constrains the development of most streams as drinking water sources, and in Missoula's case, favors the use of the groundwater as the area's drinking water supply.

VI. POTENTIAL DRINKING WATER SOURCES

Executive Summary

The Clark Fork River flows through the Missoula Valley and has a drainage area of almost 6,000 square miles. The average annual discharge above Missoula is 3,037 cubic feet per second (cfs). Irrigators in the drainage basin use up to one-fifth of the average annual flow. Hydroelectric generating facilities downstream from Missoula are the other major water users. One of these facilities, Noxon Rapids Dam owned by Washington Water Power Company, has rights to 50,000 cfs. Average annual flow at Noxon is 22,000 cfs.

The B-1 classification of the Clark Fork River would require a treatment process of coagulation, sedimentation, filtration, and chlorination in order to be used for drinking. It is estimated that the Clark Fork could supply Missoula with an average of 30 million gallons per day annually.

The Bitterroot River enters the Missoula Valley from the South and drains an area of about 2800 square miles. The average discharge at Missoula is estimated to be 2334 cfs. Irrigation demands nearly one-quarter of the total flow. Water quality constraints similar to those on the Clark Fork apply to the Bitterroot River. Painted Rocks Reservoir, located on the West Fork of the Bitterroot, is a storage facility with water currently available for purchase. The Bitterroot could not be considered a continuous supply of water unless water is released from the reservoir. A purchase agreement for 5000 acre-feet of water per month could provide enough water to meet Missoula's demand.

The use of the existing water storage and distribution system on Rattlesnake Creek was discontinued due to *Giardia* contamination in 1983. Re-establishing Rattlesnake Creek as a source of drinking water would require the construction of a filtration and treatment plant. The capacity of such a system would be from 10 to 20 million gallons per day.

Several small creeks flow into the Missoula Valley, but few maintain enough flow to be considered as a source of drinking water. Only O'Brien Creek and Pattee Creek have unallocated water available. These sources could meet a small portion of Missoula's water demand if off-stream storage is developed.

Other aquifers in the Missoula Valley, such as Tertiary sediments or fractured bedrock, do not have high enough yields to meet Missoula's water demand.

Well fields developed in the Bitterroot Valley aquifer,

south of Missoula, could yield enough water to meet Missoula's demand, but an expensive distribution system would have to be developed.

Introduction

Several potential sources of water that could be developed are within the vicinity of Missoula. The confluence of two rivers, the Bitterroot and the Clark Fork, occurs in the southwest portion of the valley and the Blackfoot River joins the Clark Fork just ten miles east of downtown Missoula. Numerous creeks, including Rattlesnake Creek, flow into the valley from the surrounding mountains recharging both the Clark Fork River system and the groundwater supply in the Missoula Aquifer. Additional groundwater is available from deeper aquifers within the Missoula area and alluvial sediments in large valleys adjacent to the Missoula valley.

Development of one or several potential sources will be limited by financial and institutional constraints. This section describes the institutional barriers that could impede the development of potential auxiliary sources. Sources for which the barriers are found to be surmountable are further analyzed in Section VI regarding their economic feasibility.

A. Clark Fork River

The Clark Fork River enters the valley from the east through the Hellgate Canyon and flows through downtown Missoula before exiting the valley at Huson. The river originates near Anaconda, Montana, at the confluence of Silver Bow and Warm Springs Creeks, 130 miles upstream from Missoula. Its drainage basin is commonly divided into three sections: the upper stretch from the headwaters to the Milltown Dam facility, the middle stretch from Milltown Dam to the confluence of the Flathead River (including the Blackfoot and Bitterroot Basins), and the lower section from the Flathead to its entrance into Lake Pend Orielle in northern Idaho. The river is used for irrigation throughout its basin, as a recreational outlet for fishing and floating along most of its reaches, and for its hydropower capacity predominantly in the lower stretches.

Gage data upstream of Missoula (U.S.G.S. Gage #12340500) reveal an average annual discharge of 3,037 cfs or 1,963 million gallons per day. Maximum flows usually occur in May or June and low flows occur in mid-winter or in late summer or early fall. The recorded low flow for this station was in September 1937, when only 340 cfs (220 mgpd) was recorded. The upper Clark Fork, including the Blackfoot drainage, contains 5,999 square miles with approximately 130,000 acres under irrigation (MDNRC,1986). The Clark Fork and its tributaries are the main source of water for irrigators, utilizing up to one-fifth of the average annual flow (463 mgpd).

Late summer irrigation diversions reduce the flow and often dry up tributaries of the Clark Fork endangering fish habitat. In response, the Montana Department of Fish, Wildlife, and Parks (MDFWP) has applied for a water reservation for the upper section of the Clark Fork to safeguard against future depletion of the water resource (MDFWP, 1986). The reservation would guarantee in-streamflows to maintain adequate fish habitat. If the reservation is approved it will not affect senior water users, as they retain first claim to water use, but permit applications after the approval of the reservation may face rejection. An in-streamflow reservation for the upper Clark Fork could guarantee minimum flows into the Missoula valley for possible consumptive uses. However, MDFWP is currently gathering data on the middle stretch of the Clark Fork for a similar reservation (MDFWP, 1987a). This type of classification may prevent access to the water resource by municipalities or other consumptive users. Current estimates for minimum in-streamflow requirements are 900 cfs in the Missoula area.

Hydroelectric generating facilities are the other chief users of water on the Clark Fork River. Milltown Dam, Thompson Falls Dam, and Noxon Rapids Dam all operate on the main course of the Clark Fork. The most limiting in terms of water rights is Washington Water Power Company's (WWP) Noxon Rapids Dam which has appropriations of 50,000 cfs (32,316 mgpd) for operation of five generating units. Average annual flow at Noxon is 21,680 cfs much lower than Noxon Rapids capacity. A 1980 MDNRC memo demonstrated that water in the Clark Fork would only be available 32 days a year in 7 out of ten years if WWP were to demand its full allocation (MDNRC, 1980). As yet WWP has not contested further permitting in the Clark Fork Basin and is unlikely to contest a large consumptive permit or reservation until all rights are decreed in the basin (WWP, 1987).

If water withdrawals the Missoula valley were limited to this small window of availability, off-stream storage would be necessary to handle demand for the balance of the year. Utilizing a tributary for storage would involve numerous obstacles such as land acquisition and an environmental assessment of the project. A raw water intake system with continuous withdrawal from the river would prove to be more feasible and less costly than additional storage development.

Recent court decisions have raised the question of water availability in the valley. Until water rights are decreed throughout the valley it is difficult to ascertain water availability. The discharge and proximity of the Clark Fork make the river one of the most feasible potential sources in the area. To replace the current water supply, an estimated 50 mgpd would be required to handle peak usage and possible population growth and expansion (MWC, 1987). Diversion of the river's water would be most feasible near its entrance into the valley at Hellgate Canyon.

Conventional treatment of the water is required because of Montana Water Quality Bureau's B-1 classification of the Clark Fork River (MDHES, 1982). Conventional treatment requires the application of the processes of coagulation, sedimentation, filtration, and chlorination. Water quality of the Clark Fork is described in Appendix E.

Without the constraints mentioned above, it is estimated that the Clark Fork River could supply Missoula with a peak supply of 50 mgpd and an annual average of 30 mgpd.

B. Bitterroot River Basin

As part of the middle stretch of the Clark Fork Basin, the Bitterroot River extends nearly 100 miles from its headwaters in the Bitterroot Range north to its confluence with the Clark Fork (see Figure 1, page 6). The broad valley is primarily devoted to agriculture with 113,000 acres under irrigation in a basin of 2.800 square miles (MDNRC, 1986). The river is also an important recreational resource for fishing and floating. The Bitterroot, near its confluence with the Clark Fork, has an average annual discharge of 2334 cfs (1509 mgpd) (Geldon, 1979). Agriculture demands more than one-quarter of the flow averaging 432 mgpd (MDNRC, 1986). Much of the diversion occurs during the summer when contribution from snow melt has disappeared and the river is at its lowest levels. The river is ungaged at its mouth, but recent sampling has measured low flows of 250 cfs (162 mgpd) in February of 1985 and 310 cfs (200 mgpd) in August of the same year (MDHES, 1985). Maintenance of in-streamflows for fish habitat may require up to 500 cfs.

The Bitterroot River and its tributaries are used primarily for irrigation and stock watering. Many of the drainages feeding the Bitterroot are already over allocated and some users lack the water for irrigation during dry, hot summers. Irrigation districts have often purchased water from Painted Rocks Reservoir to augment their dwindling supply during dry summers. Painted Rocks Reservoir is owned and operated by the Montana Department of Natural Resources and Conservation and is 90 miles south of Missoula (see Figure 1, page 6). The MDFWP has made similar purchases from the reservoir's operators to maintain minimum in-streamflow levels for fish habitat (MDNRC, 1987). Although there is sufficient flow for much of the year, the Bitterroot appears to suffer from overdrafts in the summer, decreasing the availability and reliability of its water for a municipal supply.

Constraints similar to those on the Clark Fork apply to the Bitterroot. Hydropower users may still request their full allotment, and priority users upstream will still have first access to the water. One possible alternative is purchasing water from the Painted Rocks Reservoir and releasing the water into the Bitterroot to be withdrawn near Missoula. An open system utilizing Painted Rocks Reservoir as a source and the Bitterroot River as a means of conveyance may face the problem of unregulated diversions by irrigators of the purchased water. This sort of proposal would require enforcement of diversions by a water commissioner so that individuals and agencies receive their full allotment of water. A water commissioner, as established by Montana Water Law, has the power to enforce the regulation of diversions and arrest persons interfering with the distribution of the diverted water.

The MDFWP has made purchases of water from Painted Rocks Reservoir for \$2/acre-ft used for maintaining non-consumptive, in-streamflow requirements. A long term purchase agreement for the consumptive use of its waters by a Missoula area utility may come at a higher cost. The cost of water varies considerably throughout the west but recent purchases by Albuquerque, NM (\$29/af) and Las Vegas, NV (\$150/af) demonstrate the value that is attached to the resource (WMU, 1987). MDNRC was unable to set a potential cost of the water from Painted Rocks Reservoir for this petition; however, for the purpose of developing the costs of such a project, the low value of \$2/acre-ft is used.

The Bitterroot has a water quality rating similar to the Clark Fork and would require the same level of conventional treatment. Because of periods of severe low flow the river could not be considered as a continuous water supply, unless water is purchased from Painted Rocks. The reservoir has historically released enough water to sufficiently replace the valley's water supply (Tudor Engineering, 1982). A purchase agreement of 5000 af (acre-feet) per month could provide over 50 mgpd to the basin.

C. Rattlesnake Creek

Rattlesnake Creek and its watershed encompass 79.7 square miles just north of the city of Missoula. Most of the drainage is designated as a wilderness and recreation area with the lower valley bottom devoted to residential property. The creek maintains an average annual flow of 135 cfs (87 mgpd) and provided water to the Missoula municipal water supply from 1875 until its closure in July of 1983. Currently there are some minor diversions of the creek's water for agriculture, but the majority of its flow enters the Clark Fork close to downtown Missoula near the Van Buren St. Bridge (see Figure 2, page 7).

The operator of the municipal system, Mountain Water Company, retains rights to 115,000 af of the Rattlesnake's flow, an average greater than 100 mgpd. The current capacity of the system is 36 mgpd, which equals the delivery capacity of the two 30" mains to the one million gallon storage reservoir at Waterworks Hill. One of the two mains is a wooden stave pipe and lacks efficient conveyance of water to the reservoir. Average daily use was approximately 10 mgpd when the system was in use. Since the closure of the system in 1983, no water from the creek has been supplied by MWC to Missoula area residents.

Reestablishing the Rattlesnake drainage as a water source will require the elimination or control of the Giardia contamination. Two methods of filtration, diatomaceous earth and direct filtration through a sand media, have been presented as the most effective means of treatment (SSGE, 1984). Both of these methods would require significant improvements upon the existing treatment facility. A less expensive means of providing "double barrier" protection would add ozonation to the existing processes of chlorination and sedimentation. The SSGE study showed that ozonation may not effectively provide the required double barrier treatment for surface waters (SSGE, 1984). An exemption from current water quality standards would be needed to reestablish Rattlesnake Creek as a municipal supply using only ozonation, sedimentation, and chlorination in the treatment process.

The capacity of the above mentioned conventional treatment facility (with filtration) would function at an optimum capacity of 10 mgpd. However, if MWC could obtain an exemption from requiring filtration in the treatment process, they could operate the facility at double the above capacity or 20 mgpd. These two options for using water from Rattlesnake Creek are delineated in the economic evaluation of potential sources.

D. Small Drainages of the Missoula Valley

Numerous creeks flow out of the surrounding mountains into the valley, but only a few maintain enough of a flow to be considered as a potential water supply. Many of these larger creeks are presently over allocated and diversions for municipal use could only occur when there is available water. This could require the development of an on-stream storage facility, storing water during high spring runoff.

The streams identified in the table below are the main contributors of creek water into the Missoula valley. Several other gulches and canyons lack sustainable flows that could provide a consistent source for Missoula area residents.

TABLE 3

MAIN STREAMS FLOWING INTO THE MISSOULA VALLEY

	Area (sq. mi.)	Avg. Discharge (mgpd)	Allocations* (mgpd)
Grant Creek	28.3	27.2**	105.71
O'Brien Creek	26.1	27.3**	9.89
Miller Creek	59	33.2***	36.30
Pattee Creek	13.4	8.6**	2.53

* from MDNRC, 1987b
** from Geldon, 1979
*** estimated using Geldon's method

D.1 Grant Creek

Grant Creek flows into the Missoula valley northwest of downtown Missoula near the junction of I-90 and Reserve St. At its entrance into the valley much of its flow seeps into the extremely permeable sediments of the valley. The drainage area consists of mountainous forested land in the Lolo National Forest and privately held residential and agricultural property in the lower sections of Grant Creek.

Grant Creek is used by a few residences as a drinking water supply but has never been considered as a major water supply to the rest of the valley because of its distance from the population concentration and its low discharges. The Rattlesnake and Missoula Aquifer have always been consistent sources negating the need of an alternative supply.

The creek maintains an average annual flow of 27.2 mgpd but allocated rights to the water in that drainage are four times that amount (MDNRC, 1987b). Because of the severe over allocation of water and increasing pressures from new development upon the water supply, Grant Creek cannot be considered as a feasible source.

D.2 O'Brien Creek

O'Brien Creek drains primarily Lolo National Forest land and some private agricultural property in the creek bottoms. The creek enters the valley from the Blue Mountain area of the Bitterroot Range approximately six miles southwest of downtown Missoula. It flows into the Bitterroot River one-half mile south of the river's confluence with the Clark Fork.

O'Brien Creek has not been used or considered as a source for the basin's needs because of its distance from the concentration of population and its low discharge.

Over one-third of the water in the creek is allocated for agricultural uses, either stock watering or irrigation. On paper there appears to be about 17 mgpd available for further permitting. However, present use of the creek's water is at its greatest demand when the flow is at its lowest. The source would not be a reliable water supply during late spring and summer when municipal use is also peaking.

O'Brien Creek could provide a portion of the valley's needs but would require development of an on-stream storage reservoir. Sizing of such a facility would vary according to site specifications and actual water availability. An extensive evaluation of impact upon present users would also be required to insure there are no negative affects upon existing rights. Water quality of the creek is similar to that of other small creeks in the basin.

D.3 Miller Creek

Miller Creek does not directly flow into the Missoula valley but enters the Bitterroot River approximately five miles south of the Missoula city limits. Land use in the drainage varies from agriculture in the valley bottoms, low density residences in the low hills, to commercial forested land in the higher mountains. Land ownership is shared by the state of Montana, Champion International, and the U.S. Forest Service in the majority of the drainage, while private individuals retain ownership in the creek bottom.

The creek has not been considered or used as a water supply because of its distance from the population centers and its low discharge volume.

Allocation of water rights exceed the average annual flow of the creek. New residential developments have increased the pressure on the water system, often leaving senior rights holders at the mouth of the creek without water. Because of the heavy use of Miller Creek water it cannot be considered as a feasible source of water for the Missoula area.

D.4 Pattee Creek

Pattee Creek enters the Missoula valley on the southeast limits of the city of Missoula. Pattee Canyon is used as a suburban community of Missoula with low density housing comprising much of the land use in the drainage. The state of Montana owns property in the upper end of the drainage and it is used primarily for recreation.

The creek has not been considered or used as a water source for the valley's residents because of its relatively low volumes of discharge. Residents of Pattee Canyon rely upon groundwater for their drinking water supply but utilize an aquifer separate from the Missoula Aquifer.

On the average, approximately 6 mgpd of water is available from the creek for permitting. Its flow varies seasonally and becomes appreciably low in the summer when the water would be in high demand. Development of the creek as a source would require construction of an on-stream storage reservoir. The siting of such a project would be constrained by the numerous land owners in the drainage and would not be compatible with the existing land use. Relocation of homes and families for such a small source of water will cause such a project to be termed infeasible.

E. Other Aquifer Sources

E.1 Renova Equivalent and PreCambrian Belt Rocks

As mentioned earlier two other formations in the Missoula valley have been identified as water-bearing. However, aquifer tests reveal very low specific yields and transmissivity values for the Renova Equivalent formation (Tertiary sediments) and the Pre-Cambrian crystalline bedrock (Geldon, 1979). Development of these aquifers would involve much greater production costs associated with lower yields and deeper drilling. The properties of these aquifers are presented in the section on the geohydrology of the Missoula Aquifer.

Groundwater in older Tertiary sediments is currently supplying water for domestic and agricultural needs in the hill slopes surrounding the Missoula basin. Well drillers intercepting the Missoula Aquifer sediments will usually terminate the drilling prior to reaching the deeper Tertiary sediments.

No legal or administrative constraints would hinder the development of the source. However, well yields are significantly less than what would be required to supply the Missoula valley. Because of these limitations, deeper aquifers within the Missoula valley will not be considered as feasible water sources.

E.2 Bitterroot Valley Alluvial Sediments

The Bitterroot Valley extends from Lolo to Darby, MT, a distance of 50 miles in length. The valley is bounded by the Bitterroot Mountains to the west and the Sapphire Mountains to the east, maintaining an average width of seven miles. The Bitterroot is primarily devoted to agricultural development, but several small towns occupy the valley, with Hamilton being the largest with a population of about 3000.

The valley represents a Late Cretaceous structural basin filled with Tertiary sediments. Quaternary alluvium, averaging 40 feet in thickness, overlies the Tertiary sediments along the present course of the Bitterroot River. These Quaternary deposits represent the most abundant source of groundwater in the valley but other deeper aquifers may yield similar quantities of water. An area along the floodplain between the towns of Lolo and Florence would present the best site for well field development because of its proximity to the Missoula valley.

The source is currently being used within the valley by small community water systems and individual wells for domestic, irrigation, and stock watering needs. Most of the wells are low production (<100 gpm) and meet local residential needs.

Development of the source as a potential water supply faces no legal or administrative constraints except for a examination of impact upon current users of surface and groundwaters. If potential development may demonstrate an impact upon water supplies the permit for its use may be limited or rejected.

The amount of water available from the alluvium or potential yields of wells is uncertain without testing the aquifer. It is assumed that the sediments would have the capacity of yielding enough water to match peak demand of 50 mgpd. The feasibility of developing groundwater from an outside source is constrained by the development of a large capacity pipeline into the basin. Excluding the costs required for the pipeline, obtaining easements and engineering design may impose significant barriers to development. For the purpose of providing an economic assessment of the project these constraints are ignored. A summary of alternative drinking water sources is shown in Table 4.

TABLE 4

ALTERNATIVE DRINKING WATER SOURCES

Potential Alternatives	Estimated Daily Supply (mgpd)	
	Peak	Annual Average
Rattlesnake Creek (Option 1)	7.5	10.0
Rattlesnake Creek (Option 2)	15.0	20.0
Clark Fork River	50.0	30.0
Bitterroot River	50.0	30.0
Bitterroot Wellfield	50.0	30.0
O'Brien Reservoir	50.0	30.0
Current Withdrawal from Missoula Aquifer		29.66 mgpd

Infeasible Alternatives	Constraints
Grant Creek	Over-allocated, lacks accessible water supply
Miller Creek	Over-allocated, lacks accessible water supply
Pattee Creek	Lacks reservoir site, conflicting land uses
Deeper Missoula Aquifers	Poor well yields

VII. Economics of the Potential Sources

Executive Summary

Development of an alternative source of drinking water in the Missoula Valley would involve large start up cost for water treatment facilities, adding distribution lines to unconnected areas and operation and maintenance costs. An economic feasibility analysis was performed on all administratively feasible alternatives. In order for a potential source to be economically feasible the annual cost of development must be less than .6 percent of the mean annual household income. Based on average annual income in the Missoula Valley a source cannot be considered feasible if the cost for 1000 gallons of delivered water exceeds $0.35.

The estimated costs for 1000 gallons of delivered water from the potential sources are:

a. Rattlesnake Creek - $.57 - .73
b. Clark Fork River - $.75
c. Bitterroot River - $.76
d. Bitterroot Aquifer well field - $.67
e. O'Brien Creek - $.91

None of the potential drinking water sources in the area are economically feasible. Development of a new water system will always be very expensive, but the Missoula Aquifer service area would require greater than average expense. Extensive development of service lines in unconnected areas would add nearly 28 cents to the total cost of producing 1000 gallons of water.

Currently water users in the Missoula Aquifer service area pay between 10 and 20 dollars per month for water. If another source of water is required to replace aquifer water Missoula area residents would face a substantial increase in water costs.

A. Feasibility of a Source

Currently the groundwater in the Missoula Aquifer is the sole source of drinking water for the community. The Rattlesnake drainage is the only other major source that has previously supplied large quantities of water to the area's residents. Development of an alternative source would involve large start up costs for water treatment and for improved distribution lines in unconnected areas. Distribution may represent the most intensive cost due to the relative low density of housing in the western half of the valley. Other costs that must be considered are operation and maintenance (O&M) of the treatment system and the general operating costs in administering and managing the water system.

The cost of each alternative is expressed in cost/1000 gallons treated and cost/1000 gallons delivered. This permits the examination of sources that lack the capability of producing water for the entire system. It is projected that use in the Missoula Aquifer service area is 30 mgpd or nearly eleven billion gallons annually. Design of a single treatment facility must be able to handle peak demand for the service area which is estimated to be 50 mgpd.

Methods for developing costs for alternative sources are further explained in Appendix F.

B. Rattlesnake Creek

B.1 Option 1 - Multiple Barrier Treatment with Filtration

The closure of this source in 1983 prompted MWC to perform a feasibility study on improving water treatment of Rattlesnake water. Sanderson, Stewart, Gaston Engineering (SSGE) analyzed several options available for providing quality drinking water at the lowest cost. They showed that filtration treatment would be required to be added to the present system to meet federal guidelines and provide multiple barrier treatment (SSGE, 1984). A 10 mgpd plant would represent the optimum size for a full scale conventional treatment plant. The costs were updated to 1986 dollars by Gerald Lukasick of Mountain Water Co.

Because this system would only be able to handle one-quarter of the area's demand, only that percentage of additional capital development and general operating costs will be included. It is assumed an additional source would be required to provide the remainder of water demand and therefore would include the balance of the additional capital and general operating costs.

Multiple Barrier Treatment with Filtration: 10 mgpd

Initial Capital Costs		3,400,000
Annualized Capital Costs	340,000	
O&M Treatment Costs	257,413	
Annual Treatment Costs	597,413	
Cost/1000 gals. treated water(@ 75% capacity)=$0.2182		
Capital Cost for Improving Distribution		31,674,000
Annualized Distr.(25% of system)	791,850	
Operating Costs(25% of total)	620,816	
Total Annual Costs	2,010,079	
Cost/1000 gals. delivered water=$0.7343		

B.2 Option 2 - Improvements on Current System

The capacity of the existing system on the Rattlesnake is 20 mgpd. The alternative presented here is dependent upon the exemption of the filtration treatment requirement by the state Water Quality Bureau. If MWC receives the exemption they will most likely operate the system at full capacity (MWC, 1987). The current system would require improving the sedimentation, ozonation, and chlorination facilities along with upgrading the intake system. The costs for improvements were developed by Gerald Lukasick of MWC and represent the system at 10 mgpd production. It is assumed that costs for increasing production to 20 mgpd will be minimal and are not considered.

The system only has the capacity of providing half of the water demand to the area, and therefore only half of the costs applied to the whole system are included. The balance of those costs would be derived from an additional source providing the remainder of the valley's water demand.

Existing system with minor improvements: 20 mgpd

Initial Capital Costs		2,309,700
Annualized Capital Costs	230,970	
Treatment O&M Costs	116,825	
Annual Treatment Costs	347,795	
Cost/1000 gals treated water (@ 75% capacity)=$0.0635		
Capital Costs for Distribution Improvements		31,674,000
Annualized Distr.(50% of system)	1,583,700	
Operating Costs(50% of total)	1,241,633	
Total Annual Costs	3,173,128	
Cost/1000 gals delivered water=$0.5796		

C. Clark Fork River

As a surface water supply the Clark Fork River would require conventional treatment. The plant must have the capacity of meeting peak demand periods which in the service area is approximately 50 mgpd. Average water production would only be 30 mgpd. The cost for a plant of this size is about $0.30/gallon/day to include land acquisition and plant construction (MWC, 1987). The operation of a facility including administration, management, and delivery of the water system is about $500/million gallons (MWC, 1987). The operation and maintenance of the treatment facility would represent nearly 55% of the total operational costs. Improvements on the distribution system would be required to provide service to the unconnected areas west and north of the Missoula city limits. The cost of delivering water to the 5279 households is estimated to be $6000/household.

Conventional Treatment Plant: 50 mgpd capacity

Initial Capital Costs		15,000,000
Annualized capital	1,500,000	
Treatment O&M	1,095,550	
Annual Treatment Costs	2,595,550	
Cost/1000 gals. treated water=$0.2370		
Capital Distribution Improvements		31,674,000
Annualized Distr. Improvements	3,167,400	
General Operating Costs	2,483,265	
Total Annual Costs	8,246,215	
Cost/1000 gals. delivered water=$0.7531		

D. Bitterroot River

The requirements for establishing the Bitterroot River as a surface water supply would be similar to the Clark Fork. The main distinction would be the option of purchasing water from Painted Rocks Reservoir to improve the reliability of the source. A treatment plant would have the capacity of 50 mgpd, peak demand for the Missoula valley. The area west and north of the Missoula city limits would also require distribution lines to connect these residents to the new water supply.

The MDFWP has purchased water from Painted Rocks at $2/af (MDNRC, 1987a). If the Missoula valley were to enter into a purchasing agreement, the price is assumed to be similar and that value is used here as an estimate.

Conventional Water Treatment Plant: 50 mgpd

Initial Capital Costs	15,000,000	
Annualized Capital	1,500,000	
Treatment O&M	1,095,550	
Purchased Water ($2/af, 35,000 af)	70,000	
Annual Treatment Costs	2,665,550	
Cost/1000 gals treated water=$0.2434		
Capital Distribution Improvements		31,674,000
Annualized Distr. Improvements	3,167,400	
General Operating Costs	2,483,265	
Total Annual Costs	8,316,215	
Cost/1000 gals delivered water=$0.7595		

E. Bitterroot Well Field

The Bitterroot Valley alluvium represents the nearest source of abundant groundwater outside of the Missoula Aquifer. Development of the source would require a well field encompassing about 640 acres along the Bitterroot floodplain and roughly 18 wells with an average production capacity of 2000 gpm. At full capacity these wells would be able to meet peak demand periods. The cost of well development will vary considerably depending upon geologic conditions, depth of the aquifer, well capacity, and the availability of electricity to the site. The development of wells in the northern end of the Bitterroot Valley would be similar to well development conditions for Stone Container Corporation's well field expansion for their Frenchtown Mill. These wells along the Clark Fork River typically produce 2000 gpm from the alluvial sediments of the Missoula Aquifer. Average cost for development for each well was $200,000.

Development of a well field in the Bitterroot Valley would also require a large transmission main to deliver the water to the basin. A 30" main would average $100/foot including pumping and pressure reducing stations (MWC, 1987). A well field south of Lolo along the floodplain would require over 63,000 feet or 12 miles of main. It is assumed that the water would not require treatment.

Well field O&M is expected to be similar to MWC's 1986 operational and maintenance cost of the Missoula area well field.

Well Field: 18 Wells average capacity of 2000 gpm

Initial Capital Costs		
18 Wells @ 2000 gpm		3,600,000
30" Transmission Main (12 miles)		6,336,000
Improved Distribution		31,674,000
Total Capital Costs		41,610,000
Annualized Capital Costs	4,161,000	
Well Field (O&M)	686,735	
General Operating Costs	2,483,265	
Total Annual Costs	7,331,000	

Cost/1000 gals delivered water=$0.6695

F. O'Brien Creek

No water supply system is in place on the O'Brien Creek drainage and the development of a supply would require substantial costs. Because of the relatively low discharges of O'Brien Creek and diversion of water for agricultural purposes, in-stream storage would be required to guarantee the delivery of its water. Costs for developing an in-stream storage reservoir will vary according to site characteristics, available fill material, and the costs of replacing existing roads and structures. Studies of reservoir development have not been performed in the Missoula area; however, studies of reservoir development have been performed on the Big Hole River in southwestern Montana. Costs for developing a reservoir with the capacity of yielding 25-35,000 af annually range from $27-109/af. Four different sites with a total of eight different reservoir sizes represented an average annual cost of $59/af (MDNRC, 1981). It is assumed that development costs for an O'Brien Creek reservoir would be similar to the average costs in the Big Hole River drainage.

Since O'Brien Creek is a surface water supply conventional treatment of the source would be required. The development cost of a 50 mgpd treatment facility would be similar to potential plants on the Clark Fork and Bitterroot. Improvements upon the delivery of water to residents unconnected to a central water supply would also be required.

The impact upon current users of O'Brien Creek must also be measured. The development of a reservoir on the creek should not prevent downstream users from accessing their water entitlement.

Reservoir (30,000 af yield) and Conventional Treatment

Initial Capital Costs		
Earth fill Dam Reservoir		17,700,000
Conventional Treatment Plant		15,000,000
Total Capital Costs		32,700,000
Annualized Capital Costs	3,270,000	
Treatment O&M	1,095,550	
Annual Treatment Costs	4,365,550	
Cost/1000 gals treated water=$0.3987		
Capital Distribution Improvements		31,674,000
Annualized Distr. Improvements	3,167,400	
General Operating Costs	2,483,265	
Total Annual Costs	10,016,215	
Cost/1000 gals delivered water=$0.9147		

G. Economic Feasibility of Potential Sources

In order for a potential source to be determined economically feasible the annual costs of development must represent less than 0.6% of the mean annual household income or be approximately the same as current costs. The average household income for Missoula County in 1984 was $26,447.50 (BBER, 1986). The annual cost of developing an alternative supply cannot exceed the aggregated income of the 24,000 households in the aquifer service area, or $3.8 million. The total demand for water in the service area annually averages 30 mgpd or nearly eleven billion gallons per year. The breaking point for producing this quantity at 0.6% of the average household income is $0.3494/1000 gallons (see Appendix F).

The potential water development scenarios presented above all exceed the economic feasibility of the area. Development of a new water system will always be represented by high costs, but the Missoula Aquifer service area would require even greater expense. Extensive development of service lines in unconnected areas would add nearly 28 cents to the total cost of producing 1000 gallons.

Currently water users in the Missoula Aquifer service area face moderate monthly water bills. The base rate of water use by MWC's customers is between $15 and $20 per month which represents 0.68 to 0.90 percent of the annualized mean household income. The monthly base rate for customers tied into CFWC's lines is $9.90. These sources are dependent upon water developed exclusively from Missoula Aquifer groundwater. If another source is required to replace this source, Missoula area residents would face considerably higher water costs. For example, the least costly replacement option would result in an increased expenditure equal to 1.78 percent of the annualized mean income.

It is evident that the groundwater resource in the Missoula Aquifer represents a clean, reliable, and inexpensive source of drinking water for the residents of the valley. The community could witness economic hardship if faced with developing one of the alternatives outlined in this document. The protection of the groundwater resource appears to be not only a reason for preserving a quality drinking water supply but a means to control the escalating costs of water production for the Missoula area residents. A summary of the economic feasibility of alternative sources is shown in Table 5.

Table 5

ECONOMICALLY FEASIBLE ALTERNATIVE SOURCES

Potential Alternatives	Unit Cost (per 1000 gal)	Feasible
Rattlesnake Option 1	$ 0.7343	no
Rattlesnake Option 2	$ 0.5796	no
Clark Fork River	$ 0.7531	no
Bitterroot River	$ 0.7595	no
Bitterroot Wellfield	$ 0.6820	no
O'Brien Creek Reservoir	$ 0.9147	no

Breaking Point Unit Cost = $ 0.3494/1000 gal delivered water

VIII. AQUIFER INFORMATION AND LOCATION

Executive Summary

The Missoula Valley is a closed intermontane depression bounded by mountains on four sides. The highlands surrounding the valley exhibit a ridge and ravine landscape that has evolved since the Miocene epoch about 5.3 million years ago. The climate is semi-arid with an average annual precipitation of about 13 inches and the landscape is water absorbent with very little surface runoff.

The Clark Fork River drains the Valley as it flows westward with a gradient of 10 feet per mile. Several smaller streams enter the valley from the surrounding mountains.

The Missoula Valley formed as a result of horizontal extension after Laramide thrusting which occurred between 97 and 52 million years ago. The Valley is covered by alluvial and lacustrine sediments of the Quaternary age. The foothills around the valley are composed of fine grained sediments derived from periods of deposition when the valley was internally drained during the Tertiary period 43 to 5 million years ago.

Four significant stratigraphic subdivisions are present and the first three are marked by major unconformities. They include: 1) Fanglomerates of the pre-Renova formation equivalent on the valley margins, 2) the ash-rich Renova formation equivalent which underlies the valley bottom, 3) the coarse clastic Six Mile Creek formation on the foothills, and 4) Quaternary lake silts and alluvial gravels.

Missoula Valley residents use three sources of groundwater. These sources include: 1) fractured Precambrian Belt Supergroup rocks, 2) Renova equivalent sediments, and 3) the coarse alluvium which is exposed at the surface on the valley floor. Use of the bedrock and Renova equivalent is generally limited to the valley margins because of low well yields; most of the wells in the Valley terminate in the coarse alluvium which comprises the Missoula Aquifer.

The package of coarse sediments overlying the Renova formation is called the Missoula Aquifer. The aquifer exhibits tremendous transmissivity values and yields almost 10 billion gallons of water to valley wells annually.

A. Physiography, Climate, and Geomorphology

The Missoula Valley is a closed intermontane depression which trends N55^{0}W, is approximately 20 miles long, tapering from 8.5 mi at the southern end in the vicinity of Missoula to about one mile at its northwestern end near Huson (Figure 1, page 6). The City of Missoula is located in the eastern end of the valley and covers an area of approximately 35 square miles (Figure 1). The Missoula basin is bounded by the Rattlesnake Hills to the north, the Sapphire Mountains to the east, the Bitterroot Mountains to the south and on the west and east by narrow valleys of Clark Fork River alluvium.

The climate in the Missoula Valley is semiarid. Winter is dominated by Pacific maritime air which occasionally is displaced by cold continental air draining through the Clark Fork Valley. The long-term average annual precipitation is 13.29 in (NOAA, 1985). Peak precipitation occurs in May and June, and February and March are the driest months. High intensity convective storms in July and August may also contribute significant precipitation.

The highlands surrounding the valley exhibit a ridge and ravine landscape. The landscape is relatively recent, evolving since the Miocene Epoch, about 5.3 million years ago. It is a water absorbent landscape with little natural surface runoff.

The Missoula valley is drained by the Clark Fork and Bitterroot Rivers. The Clark Fork River enters the valley from the east through the 1,500 ft deep Hellgate Canyon. The river flows westward for about eight miles meeting the Bitterroot River at Kelly Island. The Clark Fork River has a gradient of 10.4 ft/mi. The Bitterroot River enters the valley in the south central portion. It flows northwest for 4.5 miles at a gradient of 5.2 ft/mi before joining the Clark Fork River. Several smaller streams enter the valley from the surrounding highlands, including Rattlesnake Creek, Grant Creek, O'Brien Creek, Pattee Creek, Butler Creek, LaValle Creek, O'Keefe Creek and Mill Creek.

The topography of the valley floor is dominated by river terraces and glacial Lake Missoula bottom sediments. Twenty foot scarps separate the terraces and the present flood plains of the Clark Fork River and Bitterroot River (Geldon, 1979), and landscapes draped with Lake Missoula sediments form broad plains and dissected plains. Bedrock outliers like McCauley Butte also occur in the valley bottom. Other features include meander scars and oxbow cutoffs along the courses of the Clark Fork and Bitterroot rivers.

B. Surface Water Hydrology

The Clark Fork River is gaged above and below Missoula by the U.S. Geological Survey. The gaging station above Missoula is located 1,000 ft down-river from the Bandman Bridge 2.8 miles east of Missoula. The station below Missoula is located 1.0 miles down-river of the confluence with the Bitterroot River 4.5 miles west of Missoula. Both have been gaged continuously since 1929.

The gaging station above Missoula records a 5,999 mi^2 drainage area. Mean annual discharge is 3,051 cubic feet per second (cfs) (USGS, 1984). A maximum discharge of 32,300 cfs occurred on June 21, 1975; a minimum 340 cfs occurred on September 27, 1937. Monthly mean discharge based on 56 years of data (1930 to 1986) varied from 1,596 cfs in December, to 8,740 cfs in June reflecting the influence of spring rains and snow melt.

The gaging station below Missoula incorporates both the Clark Fork River and Bitterroot River and has a 9,003 mi^2 drainage area. Approximately 3000 mi^2 is drained by the Bitterroot River. Mean annual discharge is 5,547 cfs (USGS, 1984). A maximum discharge of 52,800 cfs occurred on May 23, 1948; the minimum was 388 cfs on January 18, 1933. The Bitterroot River was gaged independently from 1898 to 1905 from a bridge four miles southwest of Missoula. For the period of record discharge was 3,260 cfs (USGS, 1975). Geldon (1979) estimates the mean annual discharge for the Bitterroot River as 2,339 cfs.

Rattlesnake Creek was gaged from 1959 to 1967 at the Vine

Street bridge in Missoula. The drainage area is 79.7 mi^2. Mean annual discharge for the period was 110 cfs (USGS, 1975). Using USGS gaging data for 1959 to 1967, linear regression against the Clark Fork River from 1967 to 1977, and accounting for diverted water by the Montana Power Company from 1967 to 1977, Geldon (1979) estimates annual discharge as 135 cfs.

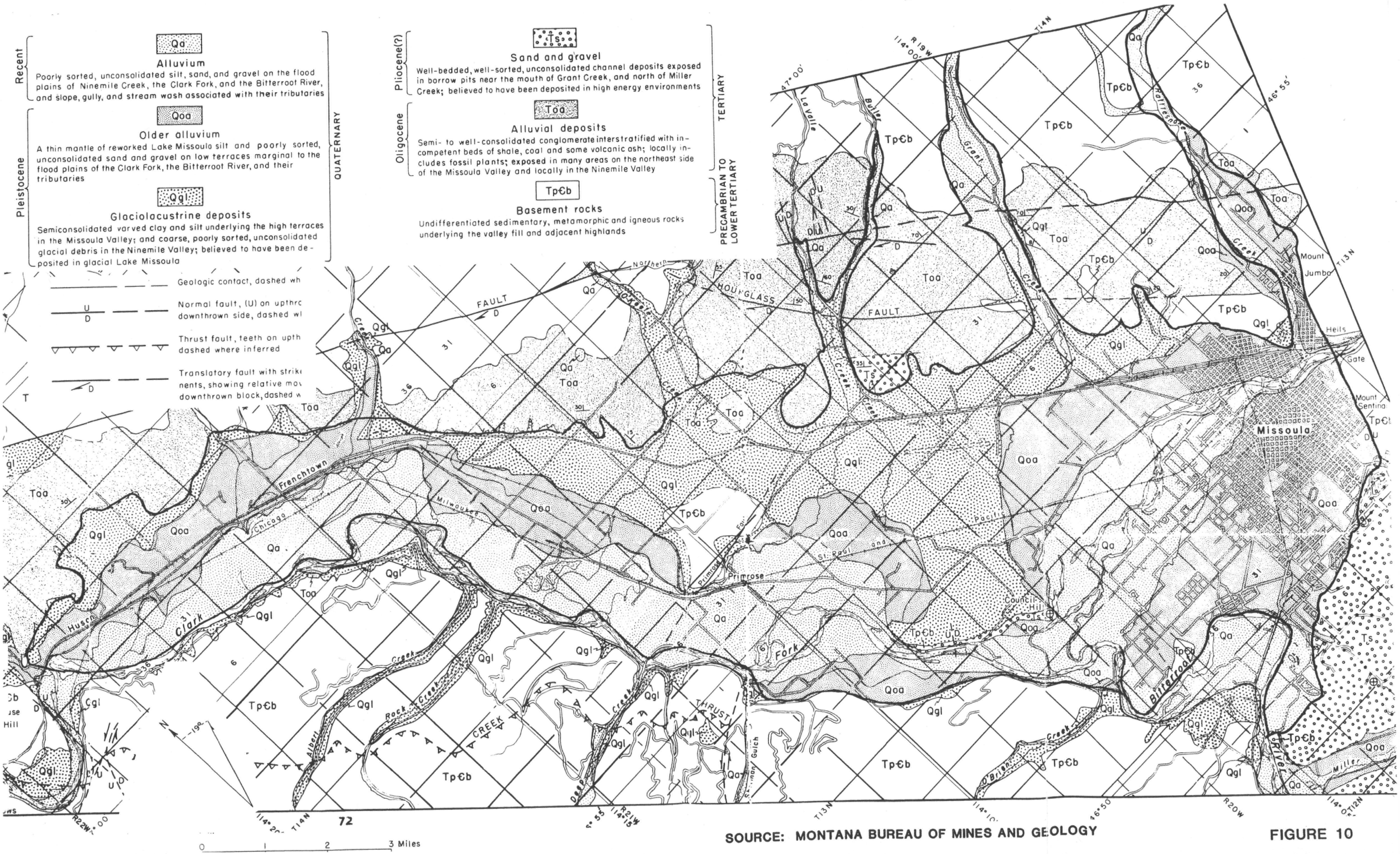
Smaller creeks such as O'Brien Creek, Pattee Creek and Grant Creek have not been gaged by the USGS. Geldon (1979) estimates discharge for O'Brien and Pattee Creeks by using mean annual precipitation and drainage area data. He then compares this to Rattlesnake Creek's discharge per square mile and mean annual precipitation. Mean annual discharges are 42 cfs for O'Brien Creek and 13 cfs for Pattee Creek. Independent stream gaging of Grant Creek by du Breuil (1983) provided a mean annual discharge of 30 cfs. No stream gaging data are available for other small creeks in the region.

C. Geology

The Missoula-Nine Mile Valley is believed to have formed as a result of horizontal extension after Laramide thrusting which occurred between late Cretaceous and middle Eocene time, 97.5 to 52 million years ago (Fields and others, 1985). The horizontal extension resulted in normal faulting which extends parallel to the faces of Mount Jumbo and Mount Sentinel and the Clark Fork Fault which is exposed on the north side of the valley (Figure 10).

The Missoula Valley is covered by alluvial and lacustrine sediments of Quaternary age, 1.6 million years ago to the present (Figure 10). The low rolling foot hills surrounding the valley floor are principally composed of fine grained sediments derived from periods of deposition when the valley was internally drained during the Tertiary period, 43 to 5.3 million years ago. The prominent Mount Jumbo and Mount Sentinel to the east and the mountain ranges surrounding the valley are composed of Precambrian metasediments of the Belt Supergroup, 0.8 to 1.6 billion

GEOLOGICAL MAP OF MISSOULA VALLEY



SOURCE: MONTANA BUREAU OF MINES AND GEOLOGY

FIGURE 10

years in age (Hall, 1968).

The Cenozoic sediments (43 million years ago to the present) of the Missoula Valley are continental clastic basin-fill deposits. The valley was filled with sediment twice and the sediment was partially removed twice. Surface exposures of Tertiary sediments are poor and infrequent. The sediments range in size from clay to coarse gravel. They unconformably overlie pre-basin Precambrian Belt Supergroup metasediments. Up to 2,500 feet of Tertiary sediments are preserved in the valley (McMurtrey, et al., 1965). A north-south diagrammatic section of the valley is presented in Figure 3 (page 8). Four significant stratigraphic subdivisions are present and the first three are separated by major unconformities. They include: 1) fanglomerates of the pre-Renova Formation equivalent which are believed to be limited to the valley's margins, ? to 43 million years, 2) the fine grained ash-rich Renova Formation equivalent which underlies the valley bottom, 43 to 20 million years, 3) the coarse clastic Sixmile Creek Formation equivalent which is found on the foot hills in places and may be overlying buried Renova Formation in the valley bottom, 20 to 5.3 million years, and 4) Quaternary lake silts and alluvial gravels, 1.6 million to the present. A summary of the Cenozoic geology taken from work by McMurtrey and others (1965), Kuenzi and Fields (1971), Fields (1981), Thompson and others (1982), Wehrenberg (1983), Fields and others (1985), and field observations in the valley by Clark are detailed in Appendix G.

D. Groundwater Hydrology

The Missoula Valley residents use three sources of groundwater. These sources include: fractured Precambrian Belt Supergroup rocks, Renova equivalent sediments, and the coarse alluvium which is exposed at the surface on the valley floor. Use of the fractured bedrock aquifer and the Renova equivalent are generally restricted to the valley margins. The sand and gravel of the valley floor is the principal source of groundwater.

The bedrock, for all practical purposes, is impermeable and wells provide water that is transmitted by fracture systems. Well yields are generally about 1 gpm. However, in the Hayes Creek area during a four hour aquifer test, a well provided 17 gpm (Bayuk, 1987). Wells finished in bedrock range in depth from 38 to over 1,000 feet. Geldon (1979) reports an average specific capacity of 0.11 gallons per minute per foot of drawdown (gpm/ft). Analysis of driller's reports in the Hayes Creek area provide specific capacities varying from 0.5 to 35 gpm/ft. Bayuk (1987) noted that the yield decreased with depth. The deepest wells, about 300 ft, had the lowest specific capacities.

The Renova equivalent occurs on the valley flanks and beneath the Missoula Aquifer. Discontinuous lenses of sand and gravel, usually less than 10 feet thick, provide water under artesian conditions. The sands and gravels are confined by silts and clays, and generally transmit less than 20 gpm (Geldon, 1979). Barclay (1986) detailed the hydrogeology of the Ninemile Valley and reported the average yield of 32 wells finished in the Renova sediments to be 11.3 gpm with a range of 0.5 to 45 gpm. Finstick (1986) found similar values for Renova equivalent sediments in the Bitterroot valley near Victor. However, in the final design of a newly constructed Mountain Water Company well on South Avenue, two zones of sand and gravel in the Renova equivalent, each three feet thick, were perforated and yielded 75 gpm when the well was developed. Geldon (1979) reports hydraulic conductivities (K) averaging 165 gallons per day per foot squared (gpd/ft^2), specific capacities of 0.51 gpm/ft, and a storage coefficient of .0001, Barclay (1986) reported an average K of 300 gpd/ft^2 with a range of 0.08 to 1,900 gpd/ft^2.

Both the Precambrian and Renova geologic material generally yield small quantities of water to wells. They are utilized for domestic supplies because other more productive sources are usually not available away from the valley bottom. In some small valleys saturated alluvium is available; however, the quantity of water is limited (Barclay, 1986). The principle interest to the majority of residents in the Missoula valley is the saturated coarse sand and gravel material which overlies the finer grained Renova sediments in the valley bottom. The coarse sediments include Pleistocene and Recent alluvial sediments and may encompass some portion of Miocene Six Mile Creek Formation at its base. Age-wise these deposits are described as Miocene (?) to Recent undifferentiated. Regardless of the difficulty in classifying the sand and gravel with respect to time, the geologic package has the common hydrologic properties which allow lumping the formation into one hydrostratigraphic unit designated the Missoula Aquifer (Table 6). This material yields over 9.7 billion gallons of water annually to wells supplying the city area and water to over 2,000 individual dwellings. Geldon (1979) reported the 150 ft of sand, gravel, cobbles and boulders have an average K of 5,100 gpd/ft^2, specific capacities of over 3,000 gpm/ft and transmissivities of over 1,000,000 gpd/ft. Aquifer storage coefficients ranged from 0.11 to 0.35.

TABLE 6

HYDROSTRATIGRAPHY OF THE MISSOULA BASIN

Hydrostratigraphic Unit	Age	Thickness(ft)	Description
Missoula Aquifer	Miocene (?) to Recent	110 to 150	Sand, gravel, and boulders with some silt and clay. Clasts well rounded. Wells yield up to 7,000 gpm.
Tertiary Sediments	Late Eocene Early Miocene (?)	2,500 to 3,000	Clay with imbedded and interbedded sand and gravel. Clay blue, gray, brown, tan and red. Local coal and volcanic ash. Wells average less than 20 gpm, up to 45 gpm.
Precambrian Bedrock	Precambrian	>10,000	Quartzite, red and green argillite, and carbonates. Water is from fractures, typically less than 1 gpm, up to 17 gpm.

E. Water Quality

Bayuk (1987) reported water quality data for the Precambrian Bedrock Hydrostratigraphic Unit. The water is a calcium bicarbonate type. The natural TDS ranges from 290 to 350 mg/l. This water quality is characteristic of a bedrock aquifer near the basin highlands that act as a recharge area to the system. It may not represent bedrock water quality 2,000+ ft below the valley floor assuming open fractures are present to transmit water to a well. It is anticipated that water would be considerably higher in TDS.

Water found in the Tertiary Sediment Hydrostratigraphic Unit is characterized by a calcium-bicarbonate type. The TDS is generally less than 500 mg/l (Geldon, 1979; Juday and Keller, 1979). Iron concentrations typically exceeded the 0.30 mg/l drinking water standards. In an attempt to describe the circulation time of groundwater in the Tertiary sediments, Geldon used the calcium:silica ratios. He found they averaged 0.64 for groundwater contained in these sediments and concluded that the water took a longer time to circulate through the system than shallower water in the Missoula Aquifer.

Water derived from the Missoula Aquifer is of good chemical quality. The water quality is well within EPA Drinking Water Standards. Juday and Keller (1979), the Montana State Water Quality Bureau (WQB), Hydrometrics (1984) and Mountain Water Company have analyzed water quality in the valley. They collected water samples from private wells, the Clark Fork River, and from faucets connected to the water distribution system.

The groundwater is a calcium-bicarbonate type water. It is moderately hard as expressed by the sum of calcium and magnesium ion concentrations. Total dissolved solids (TDS) are usually less than 350 milligrams per liter (mg/l). Chloride ion concentrations are less than 10 mg/l and sulfate is less than 30 mg/l. Ranges in pH are from 6.8 to 8.5. Geldon (1979) reports calcium to silica ratios, averaging 2.3. This implies a more rapid circulation of groundwater. The ratio decreases southwestward away from the Clark Fork River. Figure 11 shows stiff diagrams of major ions for samples collected by Clark in 1986.

Seasonally, wells near the Clark Fork River near downtown Missoula show 60% fluctuations in TDS which reflect the TDS changes in the Clark Fork River (Hydrometrics, 1984). Staff of the WQB collect an annual groundwater sample in the Missoula Valley. Water is drawn from faucets connected to the water distribution system, which represents water from some of the 27 municipal wells in the valley, and up until the summer of 1983, Rattlesnake Creek water. Mountain Water Company also monitors water

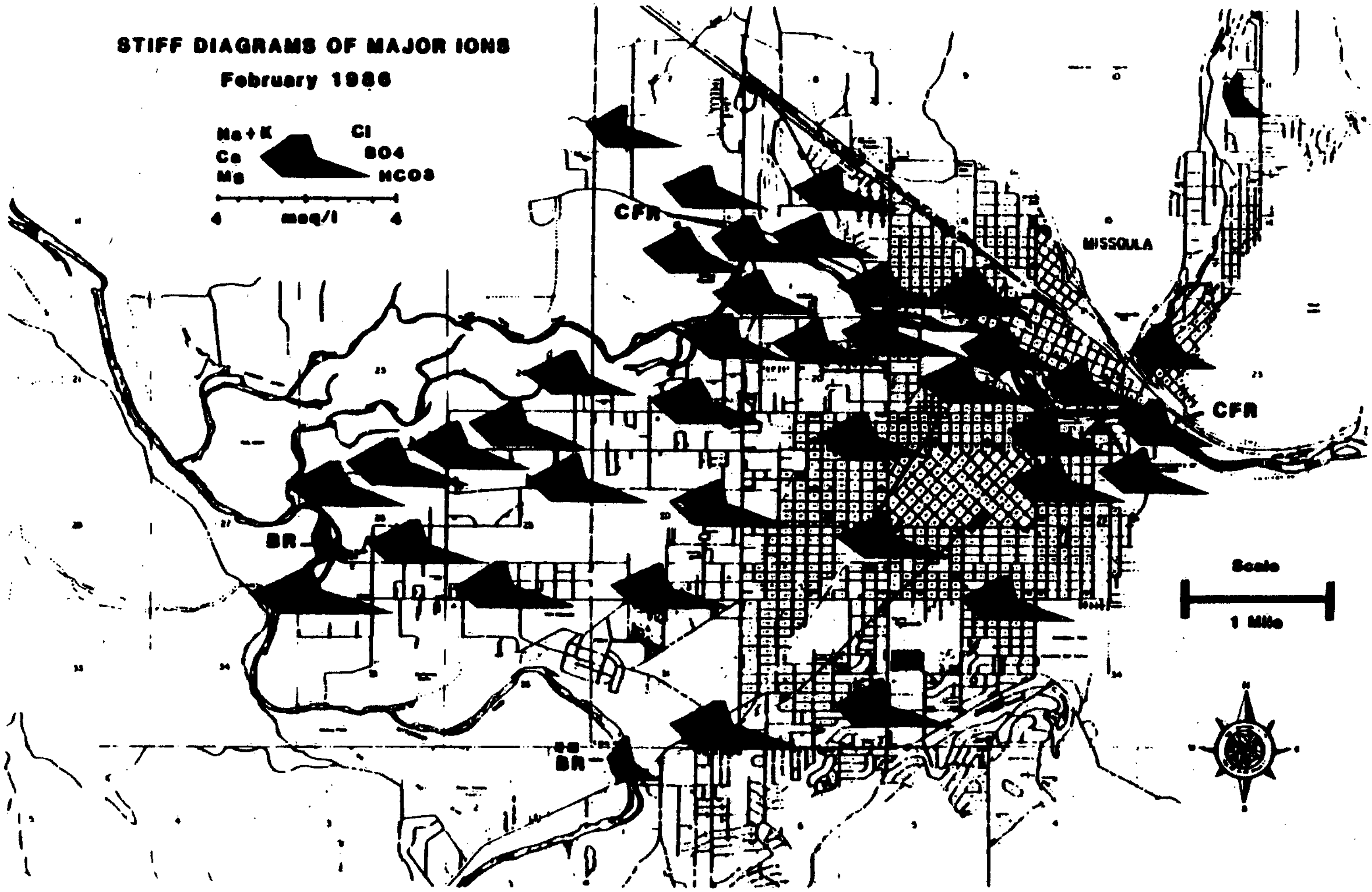

STIFF DIAGRAMS OF MAJOR IONS
February 1986
Na+K
Ca
Mg
Cl
SO4
HCO3
4
meq/l
4
CFR
MISSOULA
CFR
BR
BR
Scale
1 Mile

FIGURE 11

quality in the valley. Fifty-four bacteriological samples are collected each month which represents about 2 samples per well. Every 4 years MWC tests its wells for inorganic chemical constituents. They also sample the Clark Fork River periodically for base line data.

IX. GEOMETRY, STRATIGRAPHY AND HYDROLOGIC PROPERTIES

Executive Summary

The Missoula Aquifer averages between 110 to 190 feet thick and covers approximately 75 square miles. It is bounded by the topographic break in slope in plan view and by the lithologic contact with deep Renova formation sediments in cross-sectional view. The saturated thickness of the aquifer ranges from 50 to 170 feet. The depth to water ranges from less than 10 feet near the river to about 50 feet in the eastern part of the valley.

The Missoula Aquifer consists of three laterally discontinuous stratigraphic units. Unit one forms the surface of much of the valley floor. It is composed of 10 to 30 feet of coarse cobbles, boulders, sand and silt, but lacks abundant fine grained sediments. This unit was probably deposited in a fluvial environment.

Unit two consists of silty sandy clay with gravel and sand lenses. The relative increase in fine grained sediments of this unit is thought to be related to Pleistocene glacial lake Missoula. These fine grained lacustrine deposits appear to interfinger with coarse gravel deposits and are pinched out or missing in some areas. Unit three is dominated by coarse grained sediments: however, fine grained sediments appear to be interlayered with the coarser sediments. Most wells in the Valley are finished in unit three.

The hydrologic properties of the Missoula Aquifer vary depending on the stratigraphic unit. Units one and three exhibit very similar properties, while unit two generally has much lower values. Units one and three have values of: n= .197, Sy = .110 - .115; b for unit 1 = 10-30 ft, unit 3 = 50-150 ft.; K=10,300 - 25,500 gpd/ft^2, T= 103,000 - 1,710,000 gpd/ft. Unit two has values of: b= 40 ft; K= 200 gpd/ft^2; T= 8,000 gpd/ft. The values of m and Sy for unit two are unknown.

A. Geometry of the Aquifer

The geologic map presented in Figure 10 (page 72) shows the surface extent of the aquifer which forms the valley floor. The aquifer covers approximately 75 mi^2. Its boundaries in both plan and cross sectional view are delineated by topographic and lithologic changes. The aquifer boundary indicated in Figure 10 represents the boundary between bedrock or Tertiary sediments and the coarser sand and gravel layers of the Missoula Aquifer Hydrostratigraphic Unit.

The base of the aquifer is interpreted from two criteria: 1) the change from a coarse sand and gravel sequence to a sequence dominated by silts and clays, and 2) data on well design and well yields. Underlying Tertiary clays were expected to vary in color and dominate the lithology. The contact between the coarse sediments and the finer grained Tertiary was interpreted to also be coincident with the base of the deepest zone yielding water to wells. Generally, it was felt that the driller's on site observation of sand and gravel productivity and reduction in bore hole yield when the finer sediment was encountered, partially guided the final depth of the well and location of perforated zones. It was assumed wells in the valley typically would be perforated or left open ended in the Missoula Aquifer sediments as water is much more easily obtained from the coarse sediment.

Only a small percentage of the wells were interpreted to fully penetrate the coarse aquifer and most of these were associated with Mountain Water Company and Stone Corporation wells concentrated in the eastern and central portion of the valley.

Longitudinal and transverse geologic cross section of the aquifer were interpreted from well logs. Detailed cross sections of the Missoula valley are presented in Figures 13 - 22. The location of generalized longitudinal and transverse cross sections are shown in Figure 12.

On the average, the Missoula Aquifer is between 110 and 140 feet thick in the eastern portion of the valley and up to 190 feet thick in the central and western portions of the valley.

GENERALIZED LOCATION MAP OF CROSS SECTIONS

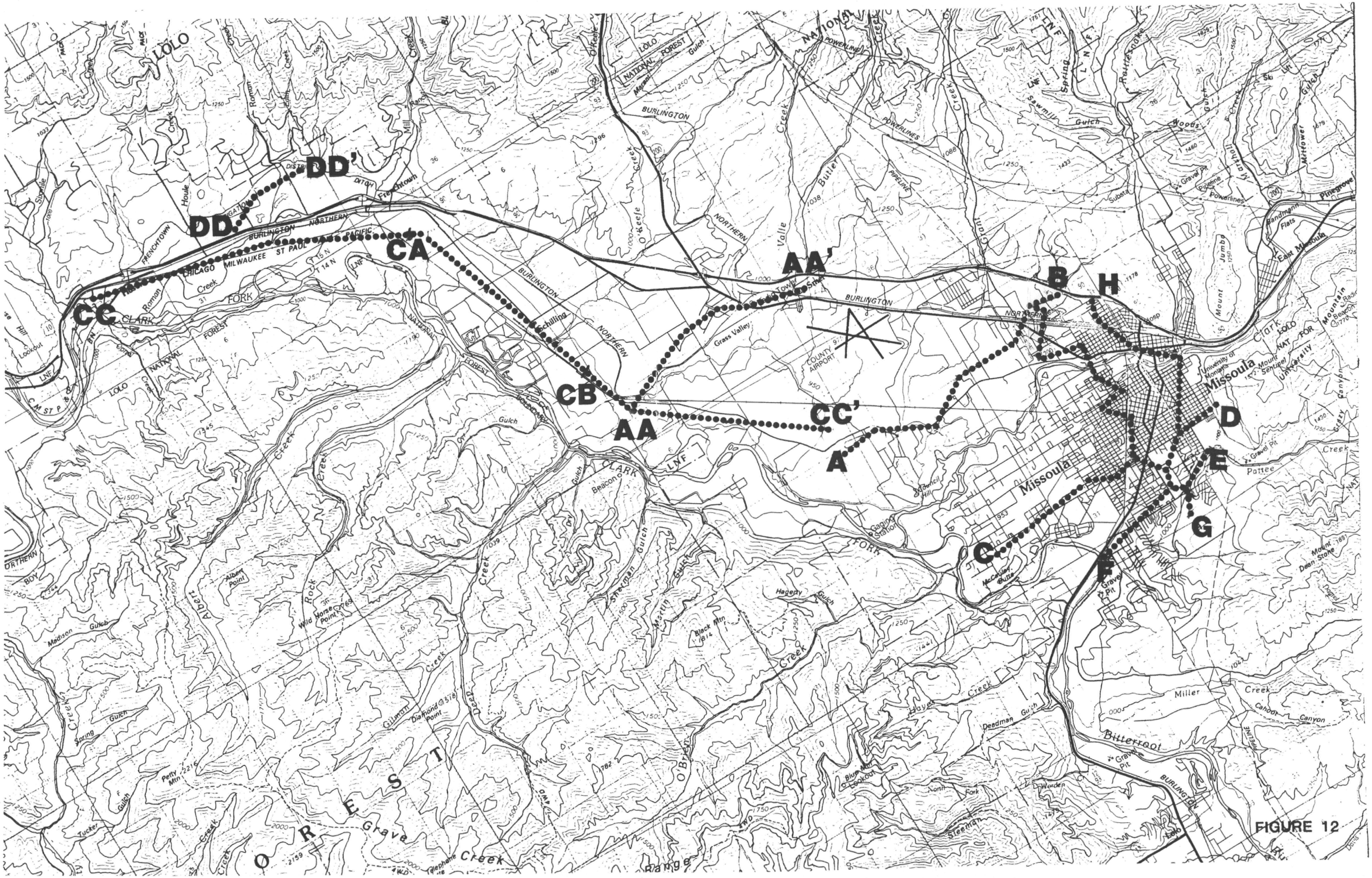


FIGURE 12

CROSS SECTION BASED ON WELL LOGS

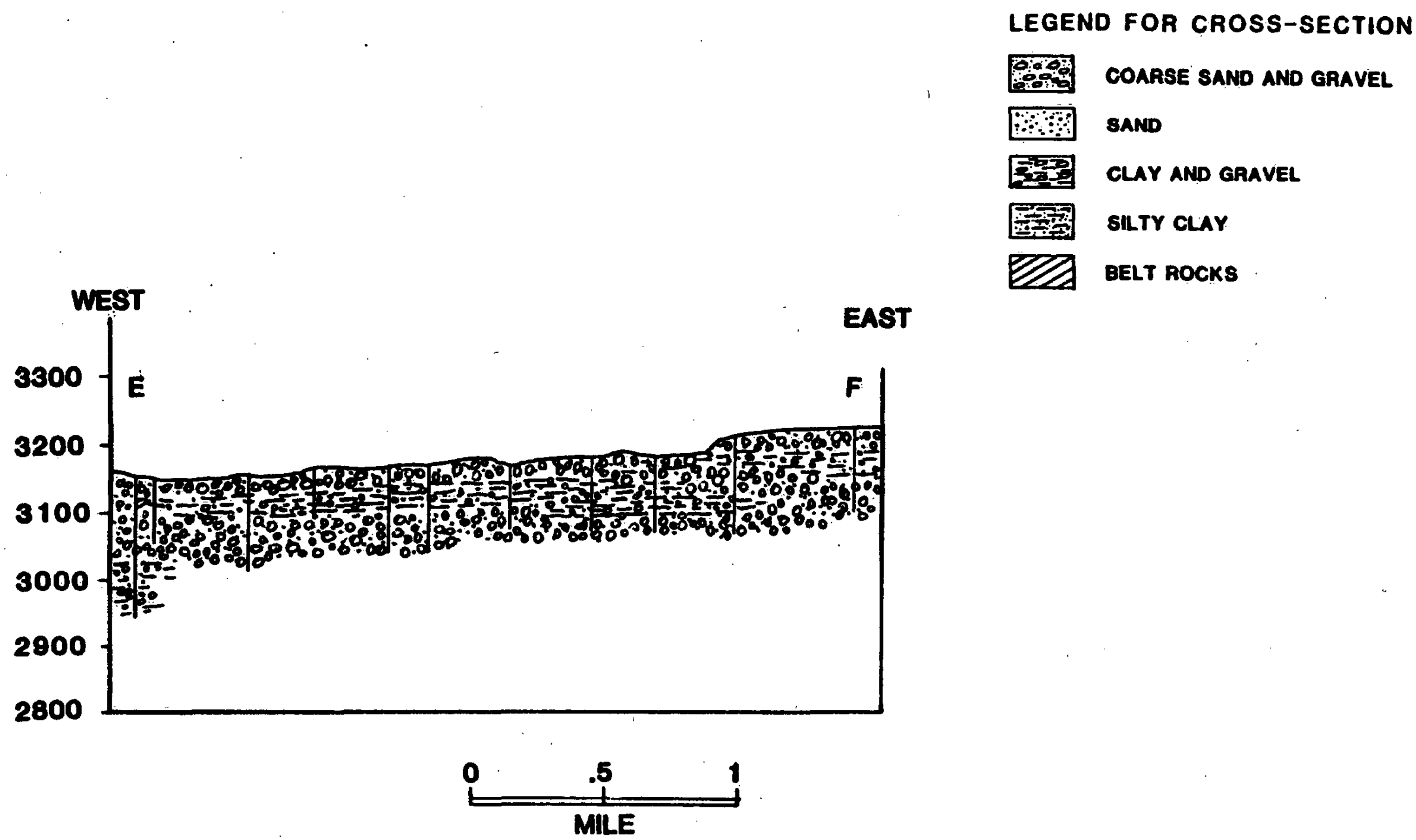


FIGURE 13

CROSS SECTION BASED ON WELL LOGS

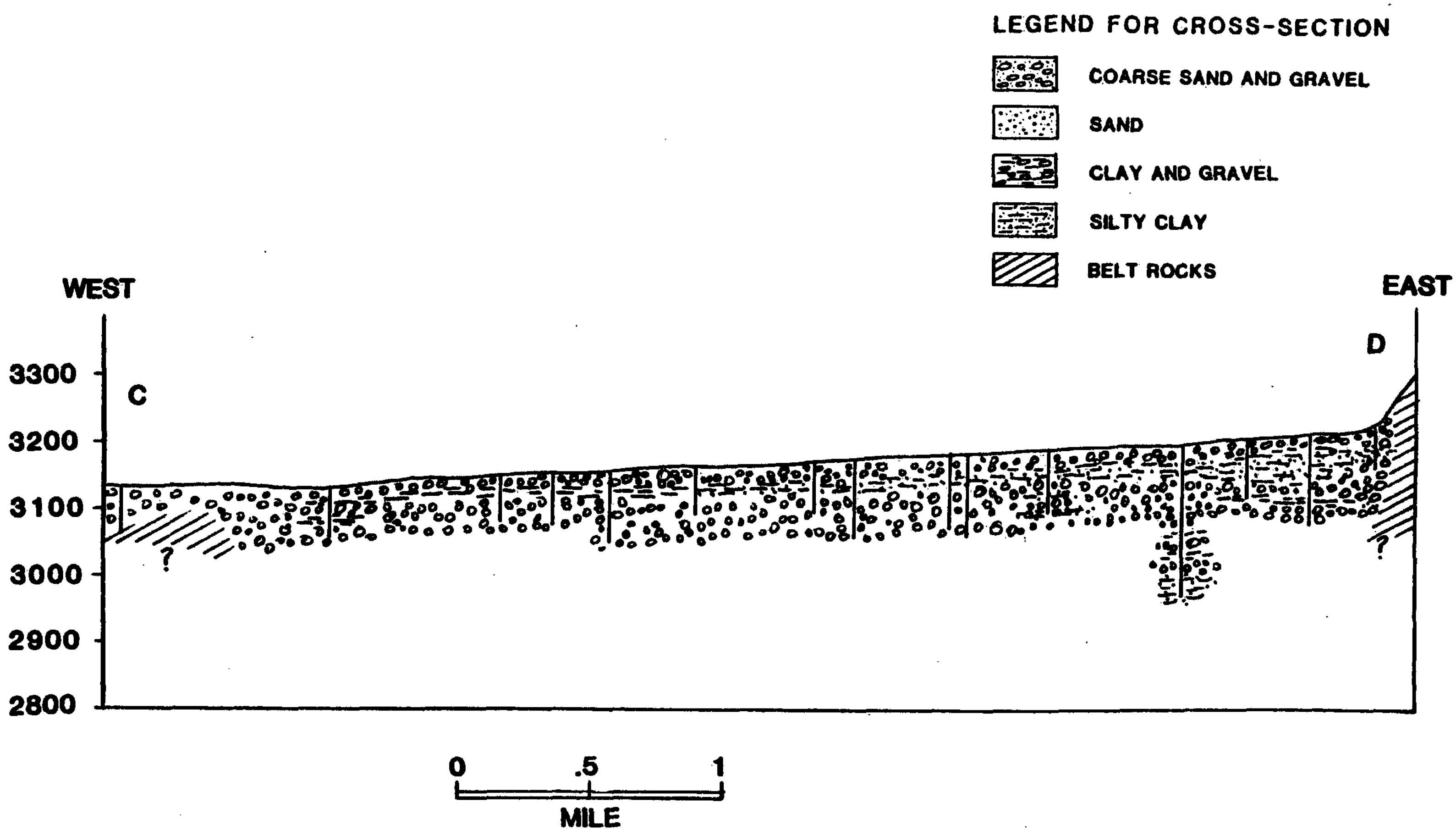


FIGURE 14

CROSS SECTION BASED ON WELL LOGS

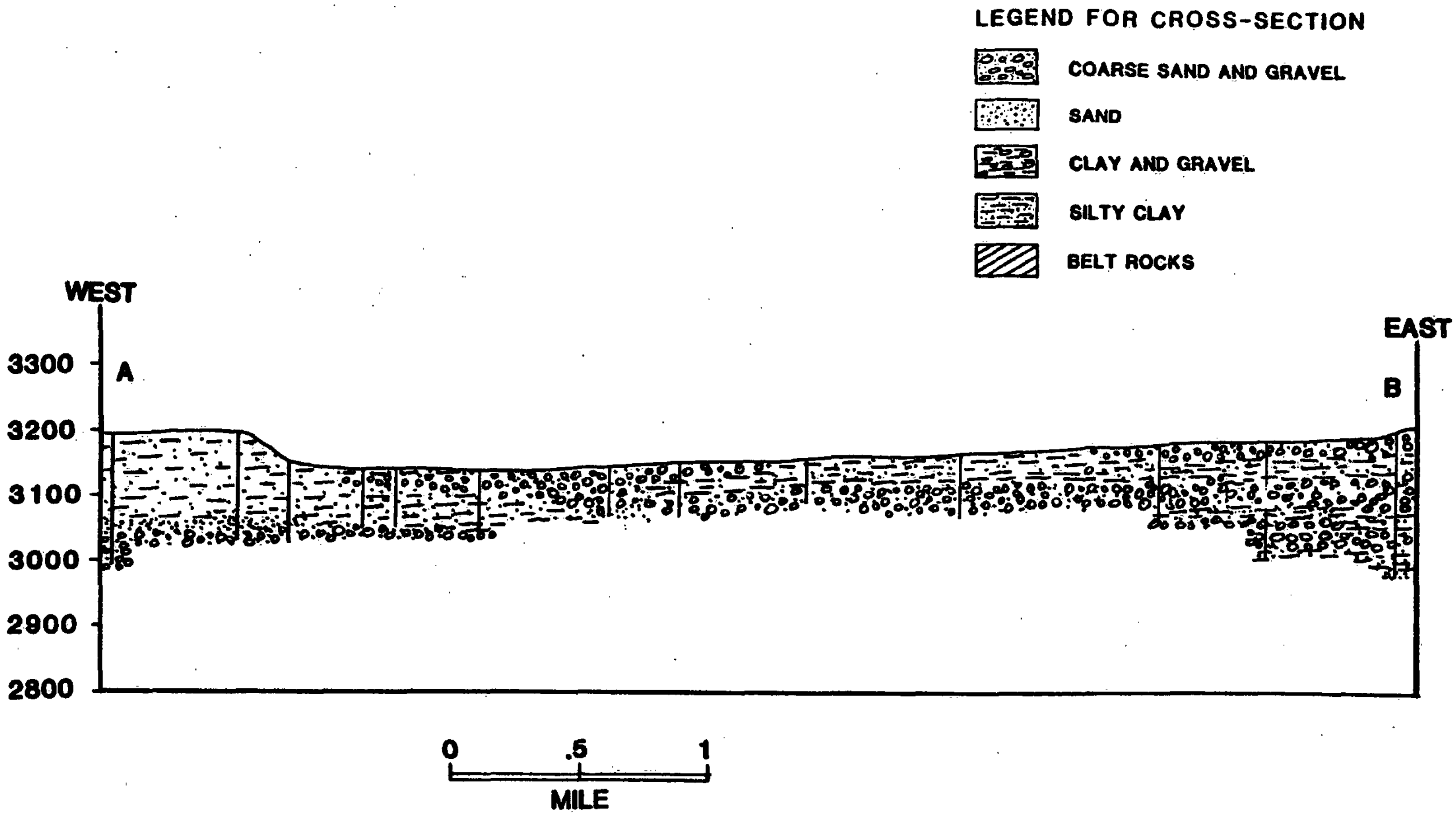


FIGURE 15

CROSS SECTION BASED ON WELL LOGS

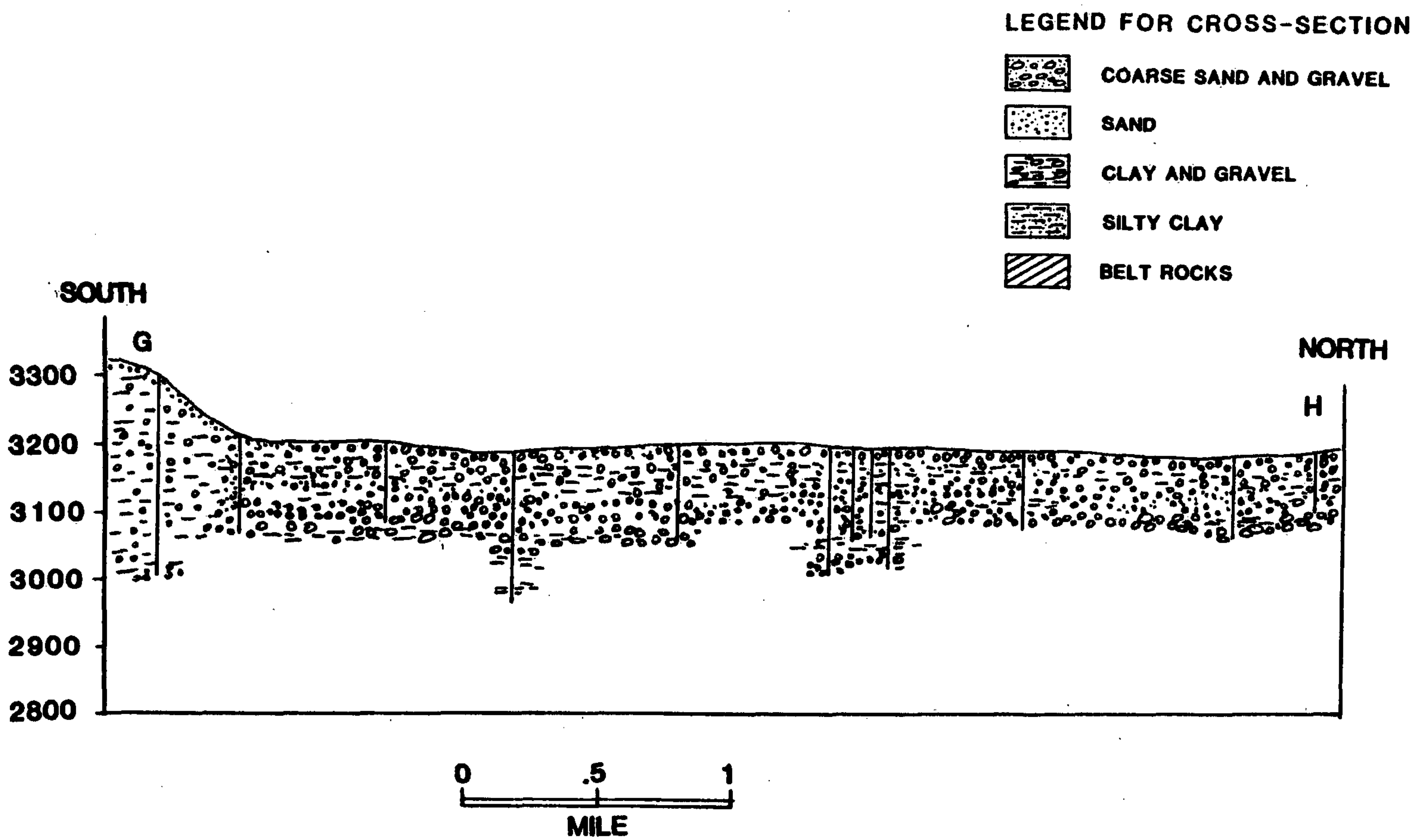


FIGURE 16

CROSS SECTION BASED ON WELL LOGS

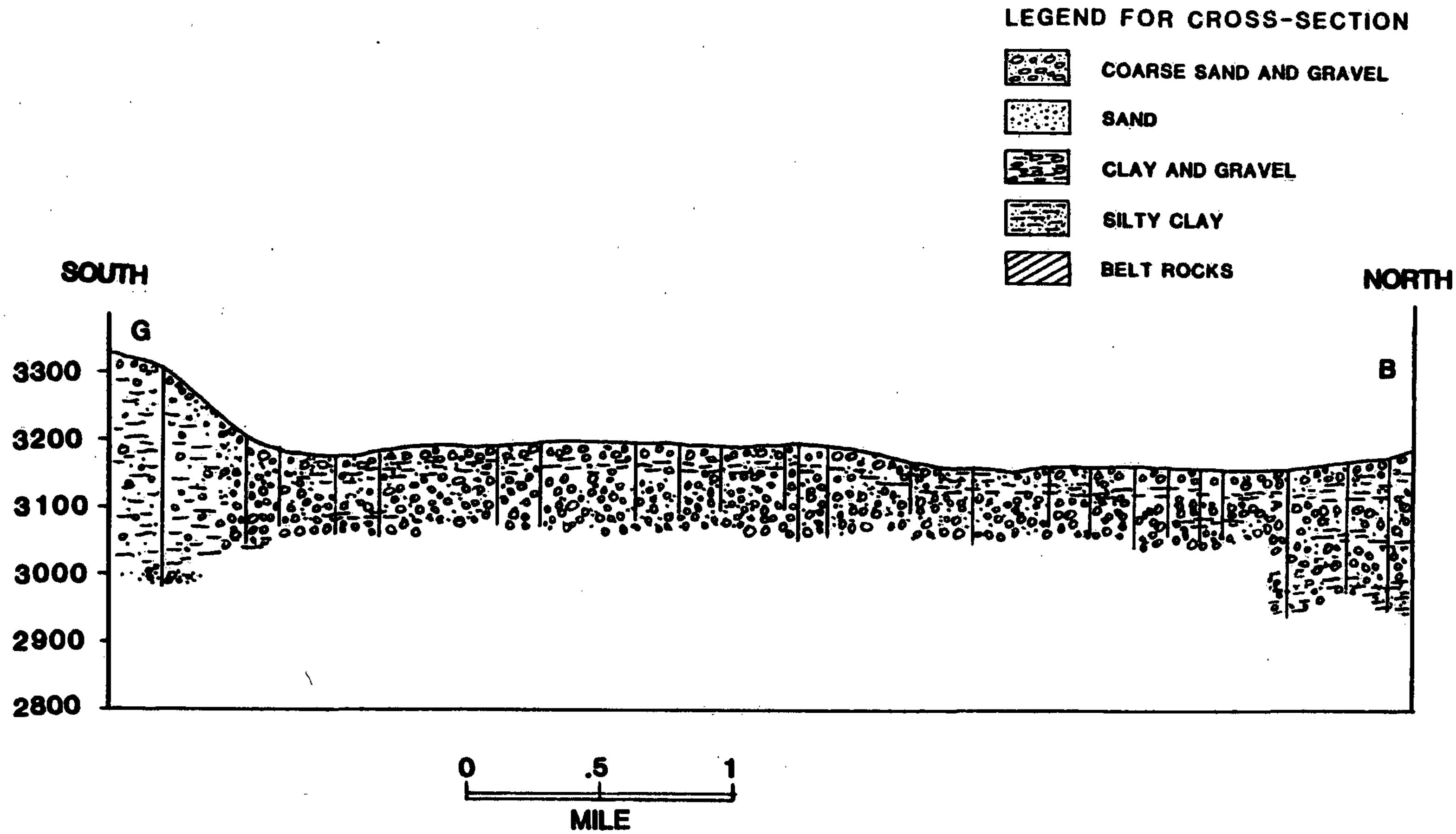


FIGURE 17

CROSS SECTION BASED ON WELL LOGS

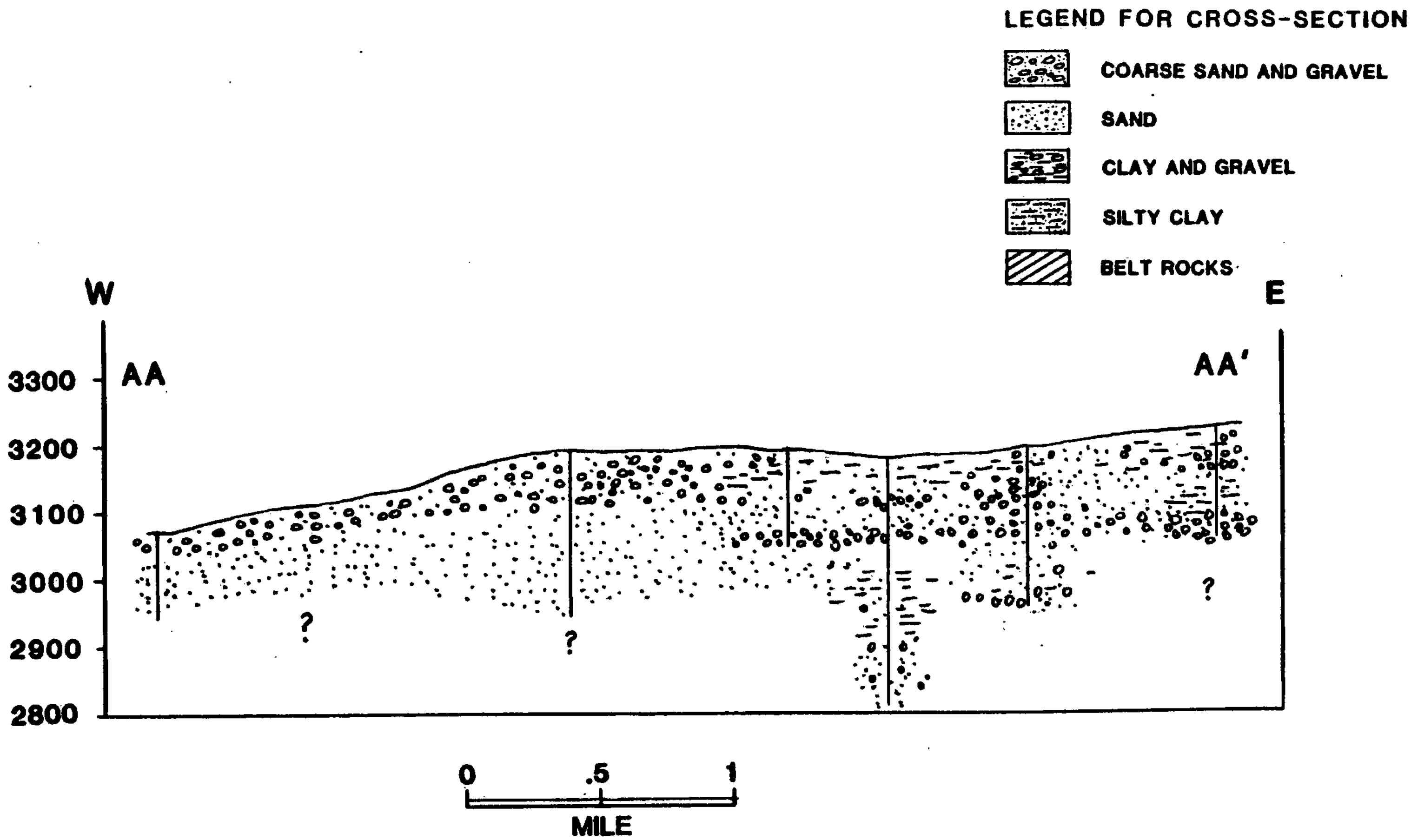


FIGURE 18

CROSS SECTION BASED ON WELL LOGS

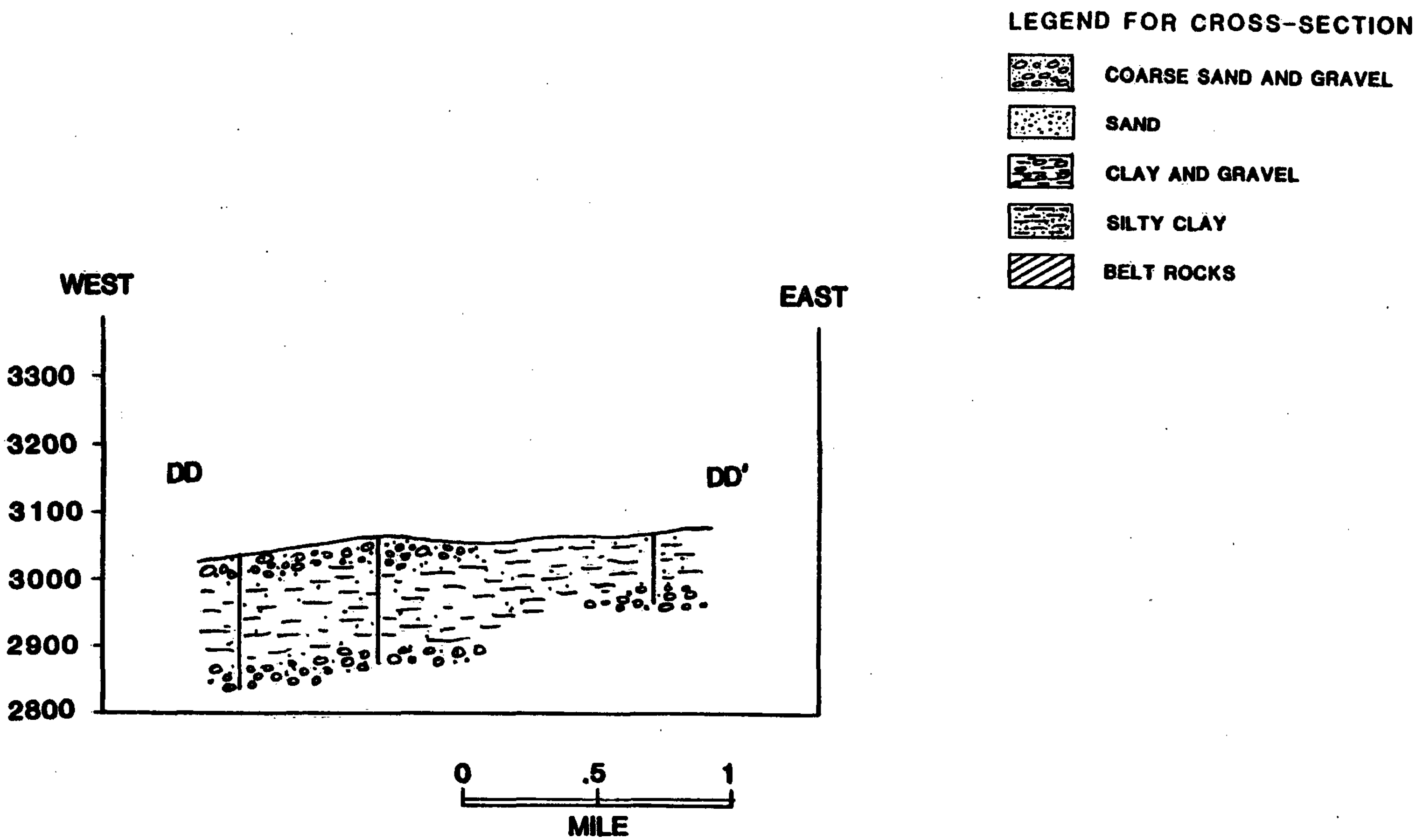


FIGURE 19

CROSS SECTION BASED ON WELL LOGS

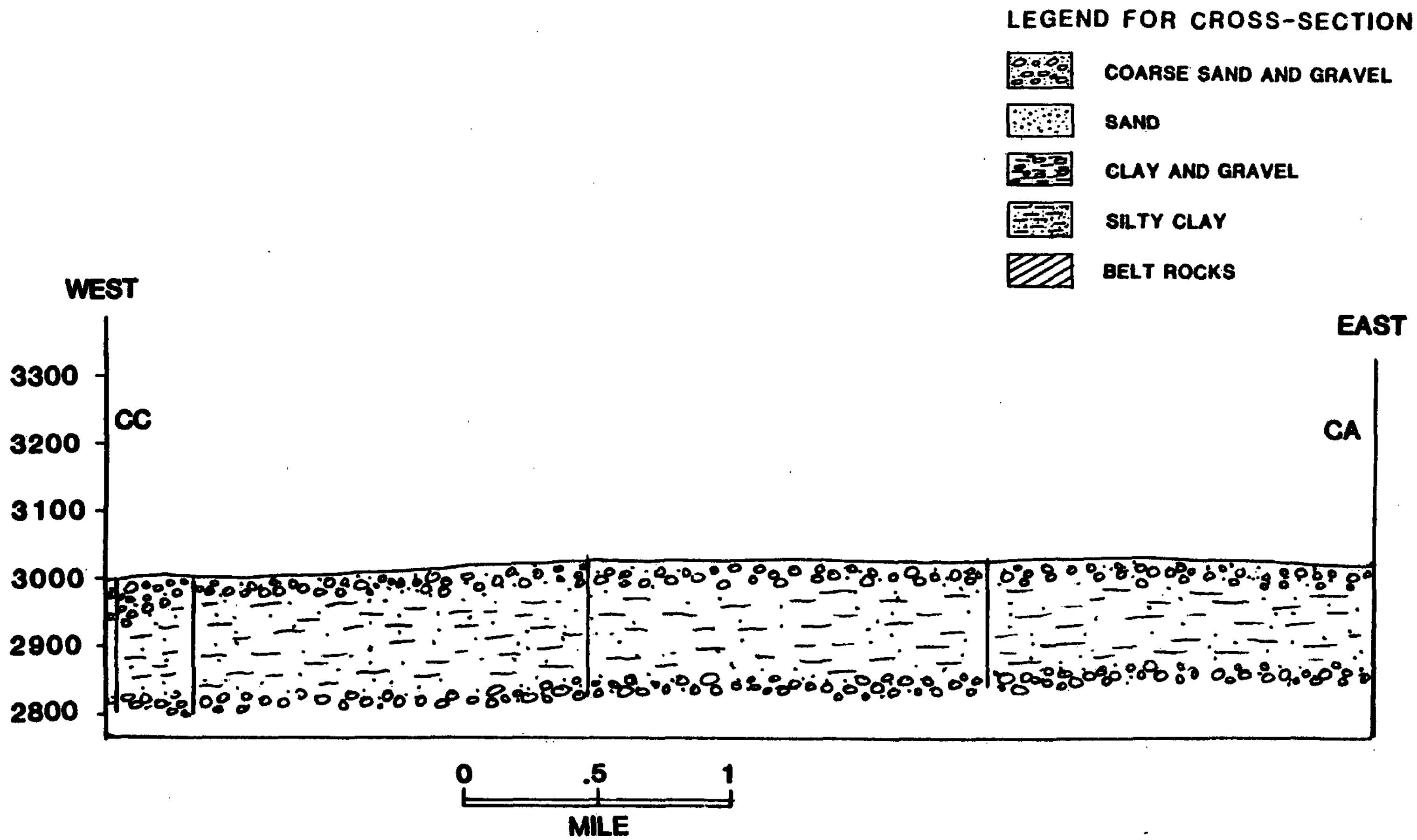


FIGURE 20

CROSS SECTION BASED ON WELL LOGS

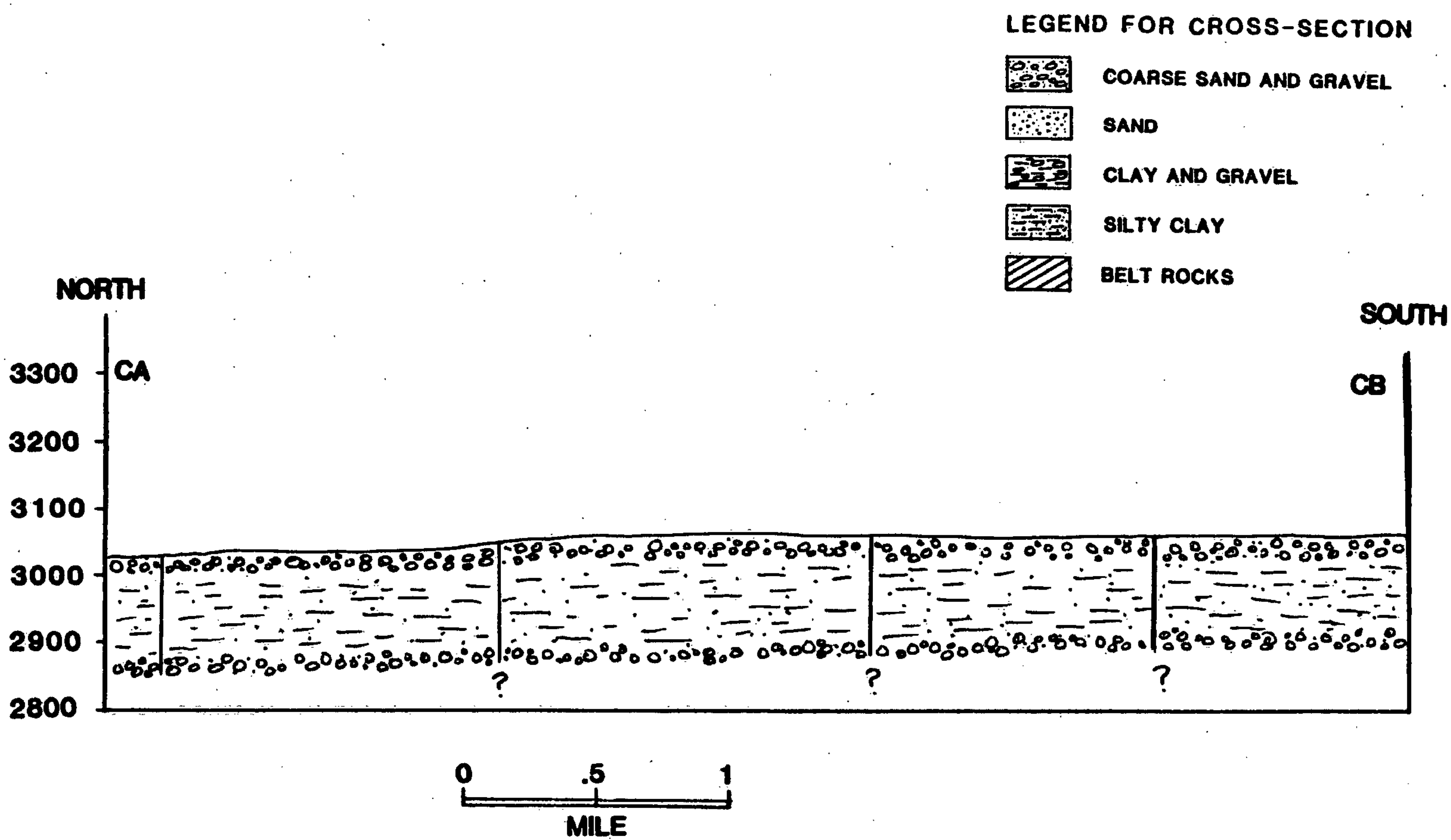


FIGURE 21

CROSS SECTION BASED ON WELL LOGS

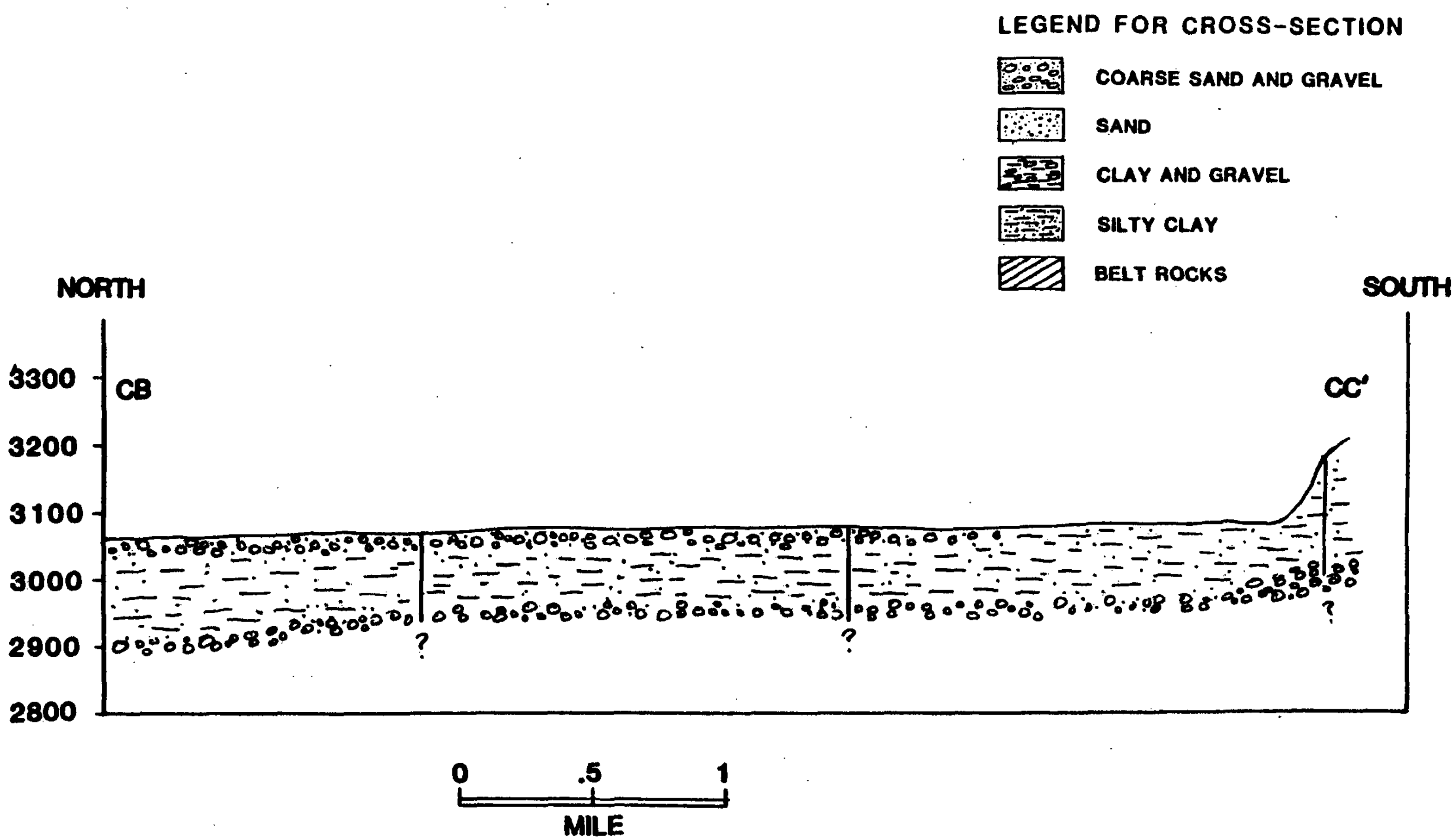


FIGURE 22

These thickness values include the unsaturated portion of the coarse geologic package. The saturated thickness of the aquifer ranges from 50 to 170 feet in the majority of the valley. The depth to water is typically 50 to 70 feet in the eastern portion of the valley, similar depths in the western and central portion of the valley, and about 10 feet near the Clark Fork River outside of the Missoula area. The water table is closest to the surface, 10 to 30 feet, adjacent to the streams and in the southwestern portion of the valley. The Missoula Aquifer sediments appear to be between 100 and 200 feet thick depending on the spatial location in the valley. However, the saturated portion of the coarse sediments is closer to 50 feet in the central valley and at the northern margin. The portion of the aquifer located where Grant Creek sediments merge with the main Missoula Valley is an exception to the generalities mentioned above. The coarse sediments are over 200 feet thick. When Grant creek is actively recharging the aquifer in the spring, the saturated portion near the mouth of the Grant Creek valley is 130 to 150 feet thick with one site recorded as 197 feet (Pottinger, 1987). In the west central portion of the valley, gravel layers are up to 50 feet thick but typically are less than 30 feet.

B. Stratigraphy of the Aquifer

Morgan (1986) interpreted a stratigraphy of the eastern portion of the Missoula Aquifer from his extensive review of driller's reports. Grimestad (1977) described the aquifer stratigraphy in the central portion of the valley. Table 7 shows the generalized Missoula basin stratigraphy.

Morgan (1986) described four stratigraphic units based solely on well log information. The first of which correlates with the Tertiary Sediment Hydrostratigraphic Unit and the other three are interpreted to be part of the Missoula Aquifer Hydrostratigraphic Unit. Morgan's (1986) description of the stratigraphic units which are part of the Missoula Aquifer are applicable to the entire aquifer and are presented in Table 8. These units

TABLE 7

MISSOULA BASIN STRATIGRAPHY

AGE	FORMATION	MAP SYMBOL*	MAXIMUM THICKNESS (FEET)	AREA IN BASIN (ACRES)	DESCRIPTION
Holocene	Active Alluvium	Qa	20	4,535	Silt, sand, gravel and cobbles in floodplains of Bitterroot and Clark Fork Rivers and Rattlesnake Creek
Holocene	Fan Alluvium	Qf	80	588	Clay, silt, sand, gravel and cobbles
Pleistocene	Landslide Alluvium	QlS	500	1,264	Clay, sand, and gravel derived from Tertiary and Pleistocene sediments
	Younger Terrace Alluvium	Qtya	40	4,344	Yellow brown to beige silt, sand and gravel underlying lower terraces along Bitterroot and Clark Fork Rivers and Rattlesnake Creek
Pleistocene	Older terrace alluvium	Qtoa	90	12,593	Yellow brown, pink and beige sand, clay, and gravel (Qs) capped with brown gravel; forms upper terraces along Clark Fork and Bitterroot Rivers and tributary creeks
	Lake Missoula Sediments	Ql	115	2,016	Varved pink clay and beige silt with yellowish sand interbeds
	Glacial till	Qt	unknown	68	Clay, silt, sand, gravel, cobbles, boulders (unsorted)
Pleistocene Pliocene	Bench gravels	QTg	245	8,056	Tan, brown, red brown, and orange cobbly gravel, silty gravel, silty gravel, silt, and sand unconformably overlying Renova Fm. and Precambrian rocks on benches flanking basin
Miocene Oligocene	Renova Equivalent	Ts	2,500	3,113	Partially to fully consolidated variegated claystone, silt stone, sandstone, conglomerate, and lignite
Cambrian	Unnamed			Mapped with Belt Series	Dolomite
	Red Lion Fm				Gray silty dolo-mite and dolomitic siltstone overlain by laminated gray limestone and siltstone
			2,800		
	Hasmark Fm				Gray dolomite
	Silver Hill Fm				Green shale and glauconitic sand stone overlain by gray lime stone and shale
Upper Precambrian (0.8 to 1.6 Billion)	Missoula Group	Per	16,000	80,183	Red, purple, pink, and green sandy argillite, siltite, argillaceous quartzite, and quartzite
	Wallace Formation		9,000		Greenish gray and gray limyargillite, impure lime stone, siltite, and quartzite

* - As found in Figure 5, page 18, Geldon, 1979

have been renumbered referring to the Missoula Aquifer Hydrostratigraphic Unit only.

TABLE 8

MISSOULA AQUIFER HYDROSTRATIGRAPHIC UNITS

Unit	Description
Unit One:	Interbedded large gravel (cobblestones to boulders), small gravel, sand, silt and some clay. Thickness from 10 to 30 ft, found at land surface and is underlain by Unit Two.
Unit Two:	Tan to Yellow silty, sandy clay with local layers of coarse sand and gravel. Thickness averages 100 to 160 ft in center of the basin, 50 to 100 ft in the eastern area and is usually overlain by Unit One and underlain by Unit Three. It is exposed at land surface in some portions of the basin.
Unit Three:	Interbedded gravel, sand, silt and clay. Unit seems to be coarser at the bottom. Thickness varies from 50 to 100 ft. in the eastern portion of the basin and is typically less than 30 ft in the central and western area. Forms the base of the aquifer.

Cross section schematics showing the sediment types dominating each unit in the valley are shown in Figures 13 - 22 (pages 83-92). A description of each unit which includes a discussion of the potential depositional environment follows.

Unit One forms the surface of much of the valley floor. It is composed of 10 to 30 feet of coarse boulders, cobbles, sand and silt and lacks the abundant fine sediments of Unit Two. It is characterized by large cobbles and boulders which drillers report as being tough to drill through. Grain size analyses of samples were performed and results are presented in Table 9 (Clark, 1986).

TABLE 9

SIEVE ANALYSES RESULTS

	Sample 1	Sample 2	Sample 3	Sample 4
Effective diameter (mm)	0.50	0.55	4.0	0.55
Mean diameter (mm)	19.8	53.5	79.7	60.3
Uniformity coefficient	44	91	30	104
Inclusive graphic standard deviation (phi)	2.31	2.92	3.18	2.74

This portion of the aquifer was probably deposited in a fluvial environment. Sediments exposed at the University of Montana stadium excavation contain very large boulders interbedded with sand, gravel and silt. This unit appears to have been deposited by aggrading river systems charged with glacial meltwaters probably during the last stages of the Pleistocene.

The overall lithology of Unit Two is a yellow to tan silty, sandy clay with gravel and sand lenses. It is impossible to determine the detailed stratigraphy from the well logs, but drillers indicate a predominance of tan clay and gravel. They typically describe the Unit as clay, sand and gravel. However, instead of cuttings of clay typically being returned during drilling through this unit, drillers observe water returned with the coarse cuttings is a cloudy tan to pink color which is recorded as the presence of clay. Samples of the finer portions of the cutting look very similar to lake sediments observed in outcrop and cuttings of Unit Two in the central and western part of the valley. Few wells are developed in this unit. Based on the gross lithology and presence of the tan clay, this unit is interpreted as being genetically related to Pleistocene Glacial Lake

Missoula sediments which outcrop in the northwestern part of the valley. Lake sediments were deposited in the basin and on the flanks of the basin. At least 36 lake fillings have been interpreted from study of outcrops of lake sediments in the 3,600 mi^2 area covered by the lake (Wehrenberg,1983). During the filling and emptying process interfingering with alluvial fans, stream channels and delta deposits produced a complicated stratigraphy. Over 150 ft of Unit Two fine grained lake sediments overlie gravel in the western portion of the valley. These sediments appear to interfinger with the coarser but still fine grain dominated Unit Two sediments found in the eastern portions of the basin. The silt and clay deposits are pinched out or missing by coarser fluvial deposits in some areas.

Unit Three is dominated by coarse-grained sediments, especially in the base of the unit. However, many well logs describe the unit as containing clay, sand and gravel. Tan fine grained sediments appear to be intermixed or interlayered with much coarser sediments. The percentage of fines to coarse material must be fairly low as wells pumping over 3,000 gpm can be developed from the eastern portion of this unit. Yields of a few hundred to a few thousand gallons per minute are more typical of wells finished in Unit Three in the central and western valley. Most wells in the valley are developed in Unit Three. The sediments probably represent channel lag, point bar and floodplain deposit from a large fluvial network. Morphologically similar deposits are found in the present Clark Fork River channel and floodplain. It is interpreted that the large fluvial system either developed from glacial meltwater in the Pleistocene time or they were deposited by late Miocene to Pliocene fluvial systems. These waters swept through the valley and deposited and reworked sediments in the system that must have aggraded in order to leave such a thick package of sediments.

In summary, the Missoula Aquifer appears to contain an interpretable stratigraphy. The coarse cobble laden soils found in much of the valley reflect the presence of Unit One. A zone dominated by finer sediment which still contains sand and gravel appears to underlie most of the basin area. The cross sections show that the thickness of this unit is highly variable and in some places it is interpreted as not being present. Underlying Unit Two is a coarse sequence of sediments which may include some finer lenses of silt and clay. It is this lower unit which is typically developed for water supply. This is apparently because it is usually saturated. Unit Two contains too much fine material for the development of productive wells and Unit One is either unsaturated or if saturated is viewed as the water most easily contaminated and thus is not developed.

C. Hydrologic Properties of the Aquifer

Characterization of the hydrologic properties of the Missoula Aquifer was accomplished by reviewing the literature, interpreting drillers' reports and conducting field and laboratory testing. A detailed accounting of data used to support the following summary of aquifer properties is found in Appendix H.

Estimates of aquifer properties are generalized in Table 10. The depositional environment of the aquifer makes it difficult to generalized hydraulic properties. As is evidenced in Figures 13 - 22, aquifer properties vary horizontally and based on the discussion above, vertically as well.

TABLE 10

ESTIMATES OF AQUIFER PROPERTIES

Missoula Aquifer Unit	n^a	Sy^b	b^c (ft)	K^d (gpd/ft^2)	T^e (gpd/ft)
1	0.197	0.115	10 - 30	10,300	103,000 - 310,000
2	---	---	40	200	8,000
3	0.196	0.10	50 - 150	10,300 - 25,500 Vertical 970 - 2,100	750,000 - 1,710,000

[a] Porosity
[b] Specific yield
[c] Saturated thickness
[d] Hydraulic conductivity
[e] Transmissivity

The hydraulic properties assigned to Unit One are based on the permeameter testing data presented by Clark (1986). Thickness data was reported by Morgan (1986). Transmissivity values were obtained by multiplication of K by b. Properties of Unit Two rely on specific capacity and saturated thickness data compiled by Morgan (1986). Hydraulic conductivity was obtained by averaging interpretations of Morgan's data and Grimestad's (1977) value for his intermediate unit. The transmissivity value was derived by multiplication of K by b. The porosity of Unit Three was derived from the permeameter work of Clark (1986). The specific yield was estimated from the permeameter data and aquifer test results conducted by Clark (1986) and the work by McMurtrey and others (1965). Aquifer thickness is presented as a range based generally on work by Clark (1986), Morgan (1986) and Pottinger (1987). Hydraulic conductivity is presented as a range. The low value corresponds to permeameter results (Clark, 1986) and the higher value is based on the average calculated from Mountain Water Company well specific capacity data. Vertical hydraulic conductivity values are reported as ranges based on Clark's (1986) aquifer tests. These values are 5 to 26 times less than the hydraulic conductivity of an isotropic homogeneous aquifer. The range of transmissivity values is based on the over all average T calculated from all specific capacity data and the higher value is based on the average of transmissivities calculated from only Mountain Water Company wells. Clark's (1986) aquifer test results bracket the selected values.

All of the values given in Table 10 are intended to serve as a general description of the Missoula Aquifer. The aquifer is composed of materials that make it highly conductive. Unit Two appears to be significantly lower in transmissive ability; however, its actual range in hydraulic properties and spatial variation throughout the study area are not well understood. Hydraulic conductivity and transmissivity values appear extremely high for Unit Three. However, operation of large production wells in this unit support the large values. Well MWC 34, located adjacent to the Clark Fork River, which pumps at 7,000 gpm, typically has less than eight feet of drawdown at the well. Other wells located away from the river area yield 250 and 2,500 gpm with one and six feet of drawdown respectively.

Generally, it was felt that aquifer properties derived from aquifer tests, permeameter experiments and driller's log analyses are most accurate. Hydraulic conductivity values calculated from sieve analyses were rejected because the techniques are intended for sands and not coarse sand and gravel, and the K values are probably too high.

X. AQUIFER RECHARGE AND DISCHARGE

Executive Summary

Groundwater flows away from the Clark Fork River in the Missoula area and towards the River west of the confluence of the Bitterroot and Clark Fork Rivers. The water table typically is at its highest elevation in June and July and at its lowest in February and March. Average groundwater velocities in the Missoula area have been estimated at six feet per day.

Water recharges the aquifer by a number of mechanisms:

1) Direct precipitation on the aquifer.
2) Discharge from adjacent Tertiary and bedrock units.
3) Recharge from influent streams
4) Storm water through storm drains
5) Septic systems through drain fields

Recharge from influent streams represents over 50% of the total recharge to the system. The Clark Fork River alone provides 46% of the annual recharge. Lateral inflow from adjacent sediments accounts for 24% of total recharge and other sources, such as irrigation and water line leakage, account for the remainder. Total annual recharge to the aquifer is estimated to be almost 88,000 acre-feet per year.

Discharge from the aquifer occurs by the following mechanisms:

1) Evapotranspiration
2) Base flow to streams
3) Pumping wells

Note: The rates of discharge from the aquifer have not been quantified.

Several streams enter the Missoula Valley and have an influent section that contributes recharge to the aquifer. Pollutants entering the stream above the influent section can reach the aquifer with recharge water.

The Clark Fork River is by far the most significant influent stream with respect to the Missoula Aquifer as it accounts for 46% of total recharge and loses an average of 14% of its flow annually to the aquifer. The Clark Fork is influent for about three miles of the aquifer. The stream source area for the Clark Fork covers nearly 7,200 square miles.

A. Recharge and Discharge

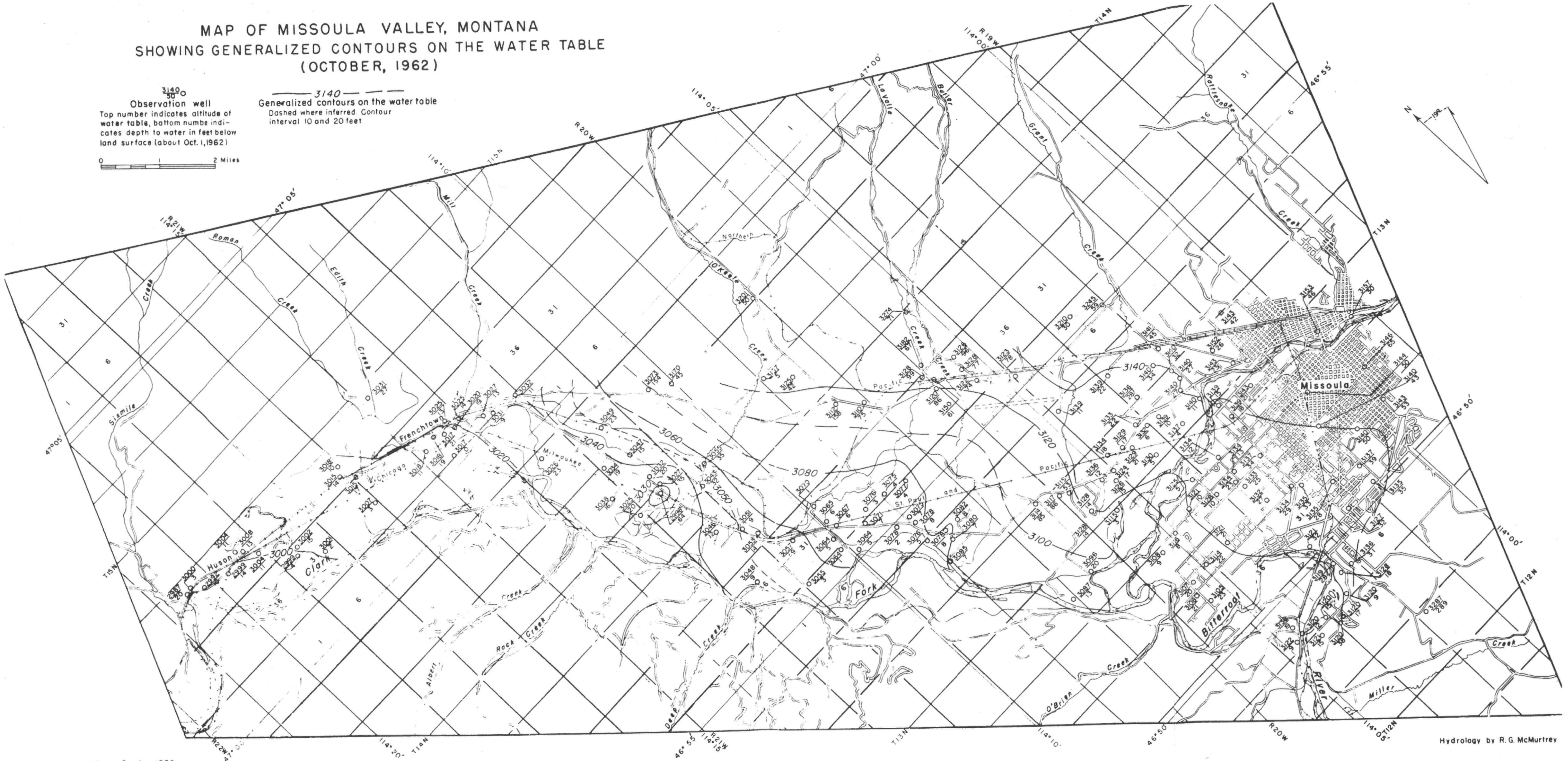
A water table map for the entire aquifer area is presented in Figure 23. This surface is based on work completed by McMurtrey and others (1965). Groundwater flows away from the Clark Fork River in the Missoula area and towards the Clark Fork River past the confluence of the Bitterroot and Clark Fork Rivers. More recent work by Clark (1986) for the Missoula area is presented in Figures 24 and 25. These potentiometric surfaces show the change in the water table from August to February. Hydrographs of a number of wells in the Missoula valley area are presented in Figure 26. They show that the water table typically peaks in June and July and is the lowest in February and March. Average groundwater velocities have been estimated at six feet per day in the Missoula area (Geldon, 1979).

Water recharges the Missoula Aquifer Hydrostratigraphic Unit by a number of mechanisms:

1. Direct precipitation on the aquifer
2. Discharge from adjacent Tertiary Sediment and Bedrock Hydrostratigraphic Units
3. Recharge from influent streams
4. Storm water recharge
5. Septic systems

Recharge by precipitation on the unconfined aquifer has not been quantified. It is believed that if recharge occurs as a result of direct precipitation, it is in the spring associated with snow melt and spring rainfall. Once July begins, probably all water not entering storm water systems is evapotranspired. By November, the ground becomes frozen, not thawing until about March.

Recharge by lateral inflow from adjacent valley sediments which outcrop at topographically higher elevations is important. Spring precipitation and the melting of winter snow pack comprise the principal recharge to the Bedrock and Tertiary hydrostratigraphic units. At the valley margins, groundwater is transmitted into the Missoula Aquifer by the adjacent upland sediments. Equipotential lines indicate a source of recharge from the mountainous terrain north of the valley (Figure 23). These sediments



SOURCE: MONTANA BUREAU OF MINES AND GEOLOGY

FIGURE 23

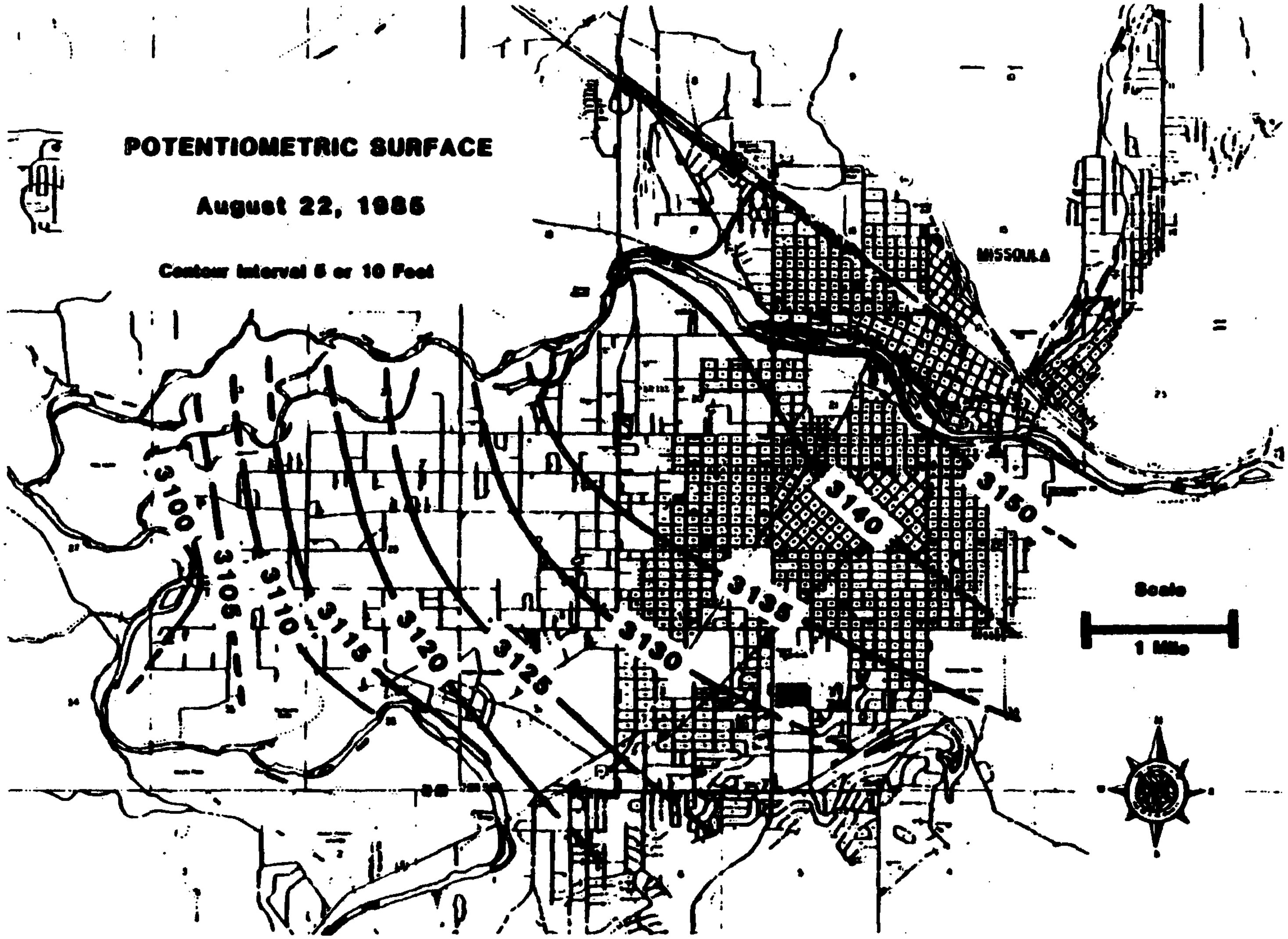
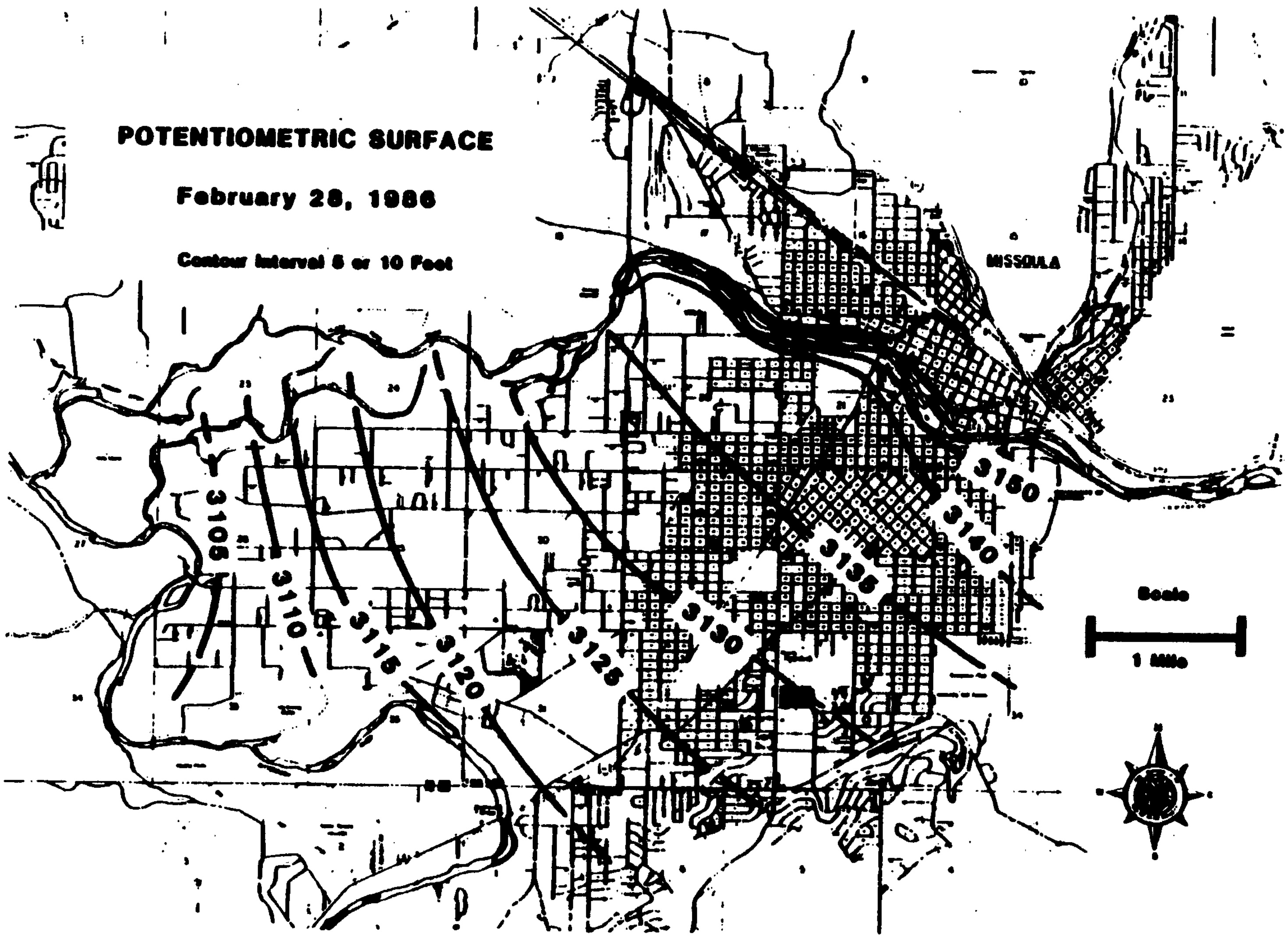

POTENTIOMETRIC SURFACE
August 22, 1985
Contour Interval 5 or 10 Feet
MISSOULA
3100
3105
3110
3115
3120
3125
3130
3135
3140
3150
Scale
1 Mile

FIGURE 24



POTENTIOMETRIC SURFACE
February 28, 1986
Contour Interval 5 or 10 Feet
MISSOULA
3105
3110
3115
3120
3125
3130
3135
3140
3150
Scale
1 Mile

FIGURE 25

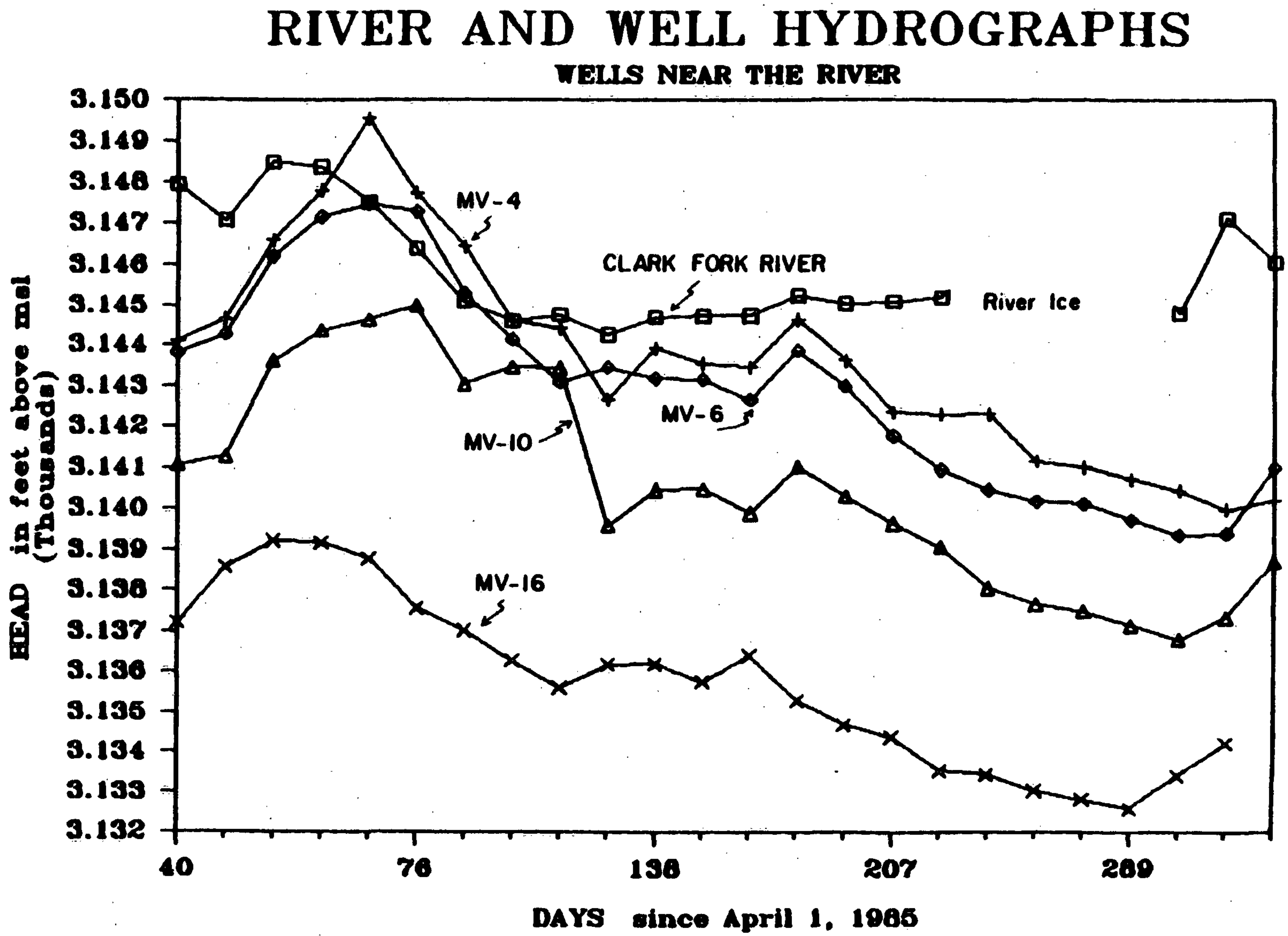

RIVER AND WELL HYDROGRAPHS
WELLS NEAR THE RIVER
HEAD in feet above msl (Thousands)
3.150
3.149
3.148
3.147
3.146
3.145
3.144
3.143
3.142
3.141
3.140
3.139
3.138
3.137
3.136
3.135
3.134
3.133
3.132
MV-4
CLARK FORK RIVER
River Ice
MV-6
MV-10
MV-16
40
76
138
207
289
DAYS since April 1, 1985

FIGURE 26

do yield small volumes of water to wells and equipotential surfaces in these sediments are higher than in the Missoula Aquifer.

The annual groundwater discharge from the northern boundary was estimated by using a cross sectional area equal to the length of the northern side of the valley from Rattlesnake Creek to Huson. For the area from Rattlesnake Creek to one mile west of Grant Creek an aquifer thickness of 75 feet, a hydraulic conductivity of 100 ft/d and a hydraulic gradient of 0.006 were used (Pottinger,1987). An aquifer thickness of 100 ft and a hydraulic conductivity value of 27 ft/d was used for the remainder of the area. The lower of the two hydraulic conductivity values was used because Unit Two sediments appear to dominate the Tertiary-Missoula Aquifer contact in the central and western portions of the valley. A hydraulic gradient of approximately 0.006 was measured from the potentiometric surface presented by McMurtrey and others (1965). Lateral inflow to the Missoula Aquifer along the northern border was estimated to be 6.8 billion gallons annually.

Some minor recharge may also occur from the east-southeastern hills and from underlying formations; however, these sources are unquantified.

The Rattlesnake Creek valley receives lateral inflow from bedrock and Tertiary sediments and from leakage from Rattlesnake Creek. Sendler (1986) estimated that 42,000 to 50,000 ft^3/d of groundwater discharged from the Rattlesnake drainage into the Clark Fork River Valley. This indicates recharge to the aquifer in the Rattlesnake Creek Valley area is at least 114 million gallons annually.

Recharge from influent streams is an important mechanism in the eastern portion of the aquifer. The Clark Fork River loses water to the aquifer over a three mile reach as it enters the valley. Clark (1986) conducted a mass balance study of the Clark Fork River which revealed an average of 14% of the flow, 36 million gallons per day, recharges the aquifer (Figure 27). Grant Creek is an influent stream which enters the valley from the north. du Breuil (1983) estimated annual groundwater

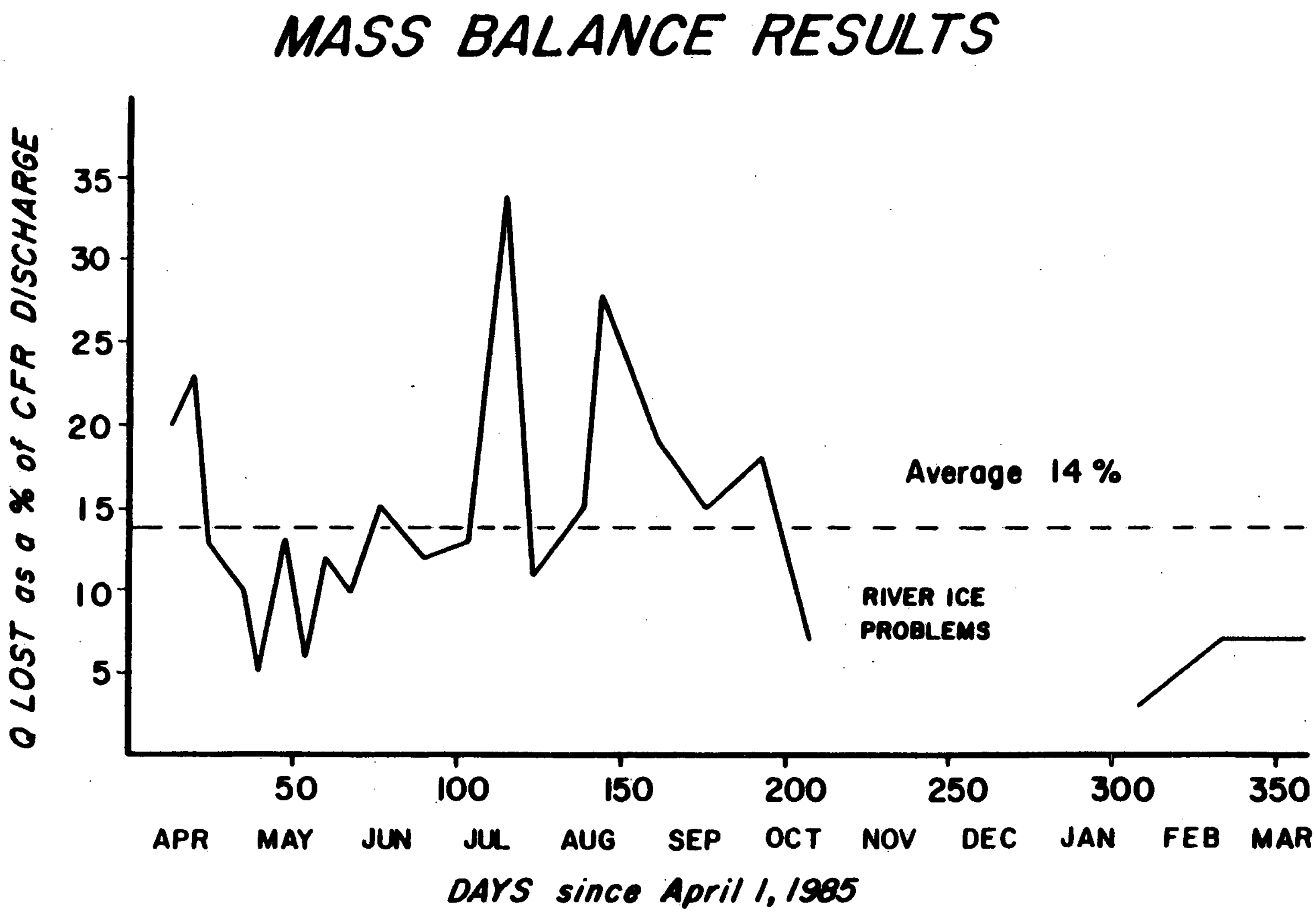

MASS BALANCE RESULTS
Q LOST as a % of CFR DISCHARGE
35
30
25
20
15
10
5
Average 14 %
RIVER ICE
PROBLEMS
50
100
150
200
250
300
350
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
DAYS since April 1, 1985

FIGURE 27

recharge from Grant Creek seepage at 1.6 X 10^9 gallons. Smaller streams such as Pattee Creek, Butler Creek, O'Keefe Creek, Mill Creek and La Valle Creek also are influent. Their recharge rates have not been quantified.

Storm water runoff in the Missoula area is channeled into 2,669 dry wells which allow water to percolate to the water table. Woessner and Wogsland (1987) estimate that 119 million gallons of water are injected annually.

Septic systems serve all but the main Missoula metropolitan area. Several thousand septic systems are found in the valley. Ver Hey (1987) measured daily loading at abut 250 gal per day per household. About 12 million gallons of septic wastes recharge the aquifer per year.

Geldon (1979) attempted to quantify the seepage from irrigation ditches and percolation of water in irrigated areas for the immediate area around Missoula. Though values have not been derived for the entire aquifer, his results provide an order of magnitude approximation of the importance of recharge from irrigation practices. He estimated irrigation practices accounted for approximately 8,500 acre feet of aquifer recharge annually.

In the Missoula area served by Mountain Water Company, water transmission line losses are estimated to be about 50%. This leakage results in over 4 billion gallons of recharge annually in the Missoula area.

Table 11 presents a summary of the sources of recharge to the Missoula aquifer.

TABLE 11

ESTIMATES OF RECHARGE TO THE MISSOULA AQUIFER

Source	acft/yr	% of total
Septic Systems	36	<0.01
Rattlesnake Creek Valley	350	0.4
Storm Water*	365	0.4
Grant Creek**	4,900	5.6
Irrigation***	8,500	9.7
Mountain Water line loss	12,300	14
Lateral Inflow, North	20,990	24
Clark Fork River	40,300	46
TOTAL	87,741	99.7

*Missoula area
**no other creeks quantified
***only in the immediate Missoula area

Water discharges from the aquifer in the following ways: evapotranspiration, wells, and base flow to streams. Evapotranspiration discharges have not been quantified. Numerous phreatophytes, cottonwood and willows, border most streams. Fields near the Bitterroot River and Clark Fork west of the confluence of the Bitterroot and Clark Fork rivers, are supplied water during the growing season by a near surface water table and are sub-irrigated.

Introductory material discusses the number and withdrawal rates of wells. No further discussion will be presented here.

The Bitterroot River receives discharge from the southwesterly flowing alluvial groundwater system. Streamflow in the Clark Fork gains from the confluence of the Bitterroot to Huson. South-southwesterly flowing groundwater discharges to the Clark

Fork River in the central and western portions of the valley. The rates of discharge have not been quantified.

Numerical Groundwater Modeling of the Missoula Aquifer

A numerical groundwater model of the Missoula area is currently under construction. Initial steady state runs required recharge from the adjacent Tertiary Sediments, Clark Fork River and Grant Creek. Discharge is assigned to Mountain Water wells and flow to the Clark Fork and Bitterroot rivers. Transmission line loss which recharges the aquifer is handled by reducing pumping rates by about one half.

Pottinger (1987) constructed a numerical flow model of a two square mile area near the mouth of Grant Creek. His model reproduced seasonal water table fluctuations by assigning proper aquifer properties, allowing Grant Creek, the Clark Fork River and lateral recharge from the northern boundary with the Tertiary sediments to recharge the aquifer. He also developed a solute transport model which predicted the migration paths of two herbicides which contaminated local wells.

To date, models support the identified sources of recharge to the Missoula aquifer in the Missoula area. Additional modeling efforts will occur in the Missoula area over the next year.

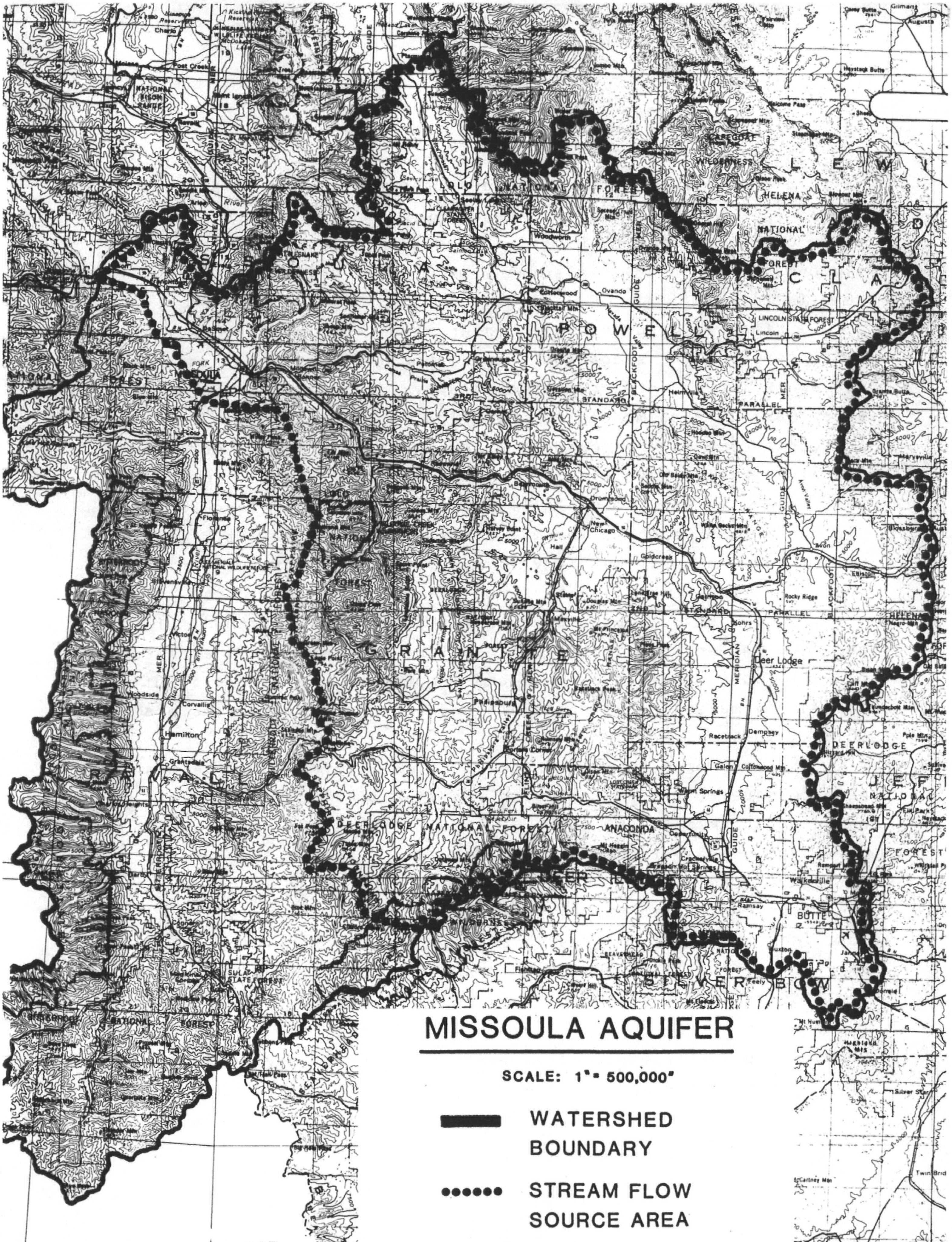
The Missoula Aquifer receives recharge from a number of influent streams. Sendler (1986) estimated that groundwater discharge from leakage from Rattlesnake Creek and groundwater discharging to the Missoula Aquifer to be 42,000 to 50,000 ft^3/d. du Breuil (1983) attempted to quantify the recharge to the aquifer contributed by Grant Creek. His work showed that about 4,900 acft were recharged annually. Most other small streams entering the Missoula Valley are influent in all or part of their reaches. They certainly contribute recharge to the aquifer system; however, the recharge rates have not been quantified. The source areas for these streams are located within the aquifer recharge area. These smaller drainages are identified in Figure 1 (page 6). However, the most important source area in terms of the quantity of aquifer recharge is that of the Clark Fork River. It is the focus of this section.

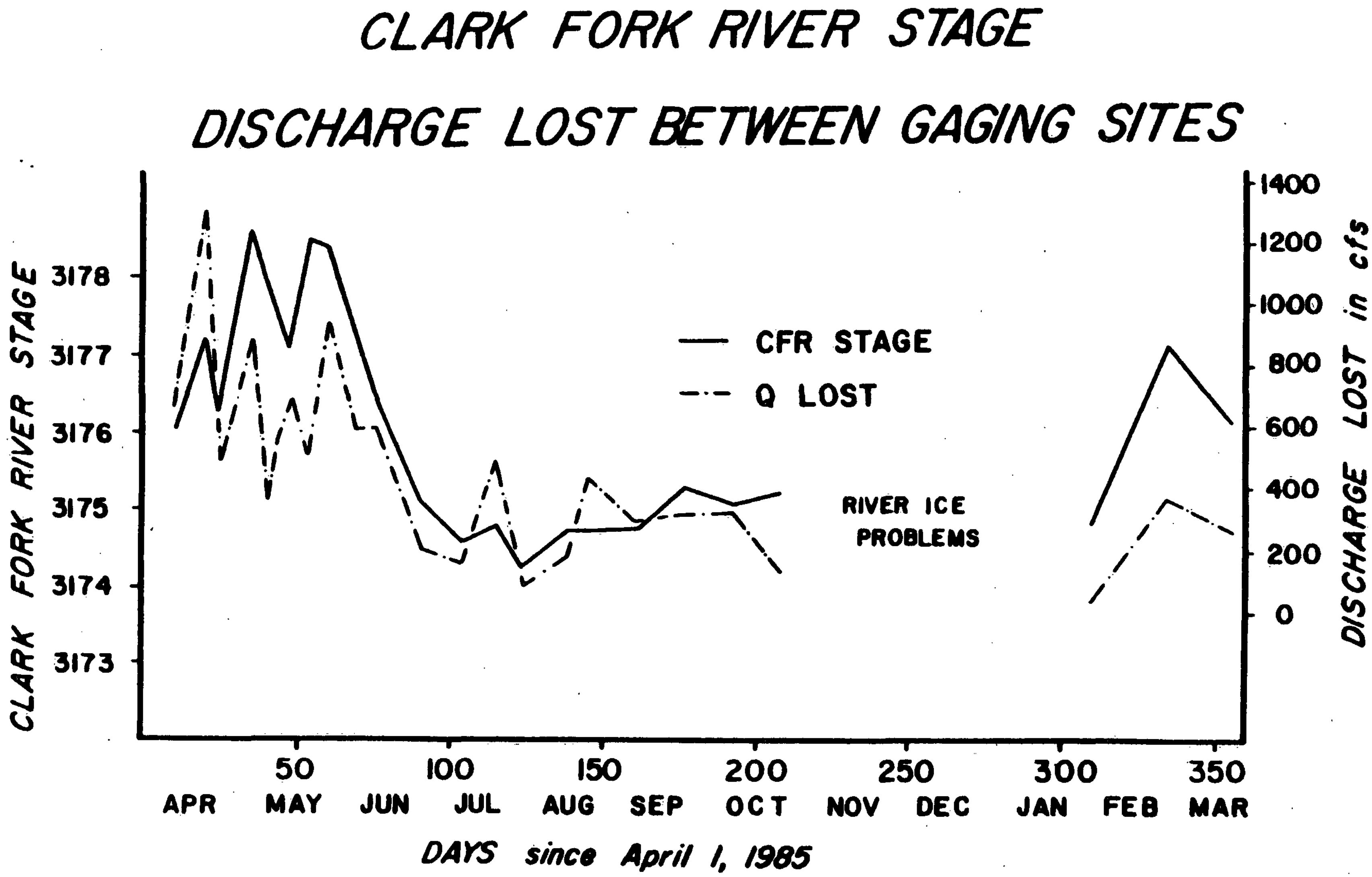
The Clark Fork River is an influent stream over about three miles of aquifer. Clark (1986) prepared a Master's of Science thesis which quantified the stream loss. The streamflow source area for the Clark Fork River above Missoula covers approximately 7,200 mi^2 (Figure 28). A summary of Clark's methodology and results follows.

Surface water/groundwater interaction was investigated by interpreting river stage and water table fluctuations, comparing surface water and groundwater chemistry, developing a surface water mass balance model, interpreting aquifer test data for the influence of a river recharge boundary and numerically modeling the river-aquifer system.

In April 1985, Clark initiated a study of the stage versus discharge relationships for the Clark Fork River and Rattlesnake Creek. He expanded the study in May to include water diverted from the Clark Fork River by three irrigation diversions. In June, two locations were added on the Bitterroot River. All gaging sites are located at bridges. He also monitored a number of wells adjacent to the river and throughout the east side of the valley measuring water levels and water quality parameters (Clark, 1986).

The discharge lost from the river calculated from the mass balance equation is presented in a number of figures which are based on Clark's (1986) work. Figure 29 shows the relationship of discharge lost from the Clark Fork River versus the time April 1, 1985 through May, 1986. In addition, the stage measured as the river enters the valley is included to show how discharge lost from the river relates to stage. The discharge lost generally coincides with river stage, varying from 1,315 cfs on April 20, 1985 to 45 cfs on February 3, 1986. The figure shows that the peak in discharge lost from the river is before peak river stage. A possible explanation is that the river bed was "flushed clean" by an early April discharge event. The Clark Fork River discharge increased from 2,170 cfs on April 6 to 5,340 cfs on


MISSOULA AQUIFER
SCALE: 1" = 500,000"
WATERSHED BOUNDARY
STREAM FLOW SOURCE AREA
MISSOULA
POWELL
GRANITE
DEERLODGE NATIONAL FOREST
ANACONDA
Deer Lodge
BUTTE
Hamilton
Corvallis
Woodside
Ovando
Lincoln
LINCOLN STATE FOREST
Drummond
Goldcreek
Racetrack
Galen
Warm Springs
Walkerville
Ramsay
Avon
Elliston
Marysville
Helmville
Woodworth
Philipsburg
DEERLODGE
SILVER BOW
HELENA
NATIONAL
FOREST
Augusta
Victor
Florence
Darby
Post Creek



CLARK FORK RIVER STAGE
DISCHARGE LOST BETWEEN GAGING SITES
CFR STAGE
Q LOST
RIVER ICE PROBLEMS
CLARK FORK RIVER STAGE
3173
3174
3175
3176
3177
3178
DISCHARGE LOST in cfs
0
200
400
600
800
1000
1200
1400
50
100
150
200
250
300
350
APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR
DAYS since April 1, 1985

FIGURE 29

April 19, 1985. This increase may have removed fine material and algae, which allowed maximum river bed leakage with a relatively high river bed permeability.

The position of the water table relative to the river surface also seems to control leakage rates (see Figure 30 for the location of the wells). During lowest groundwater levels and low river levels on February 3, 1986, the gradient between MV-34 and the river surface was 0.15 (25.2 feet of head difference in 172 feet). Between MV-36 and the river on the same day the gradient was 0.37 (23 feet of head difference in 62 feet). By May 5, 1986, as both river and groundwater levels increased, the gradients decreased to 0.12 at MV-34 and 0.34 at MV-36. This suggests that at high flows the gradient between the river and water table decreases. Although the observed gradient changes are small, the gradient may influence leakage rates most at low groundwater levels. If true, this theory is probably applicable in late July and late August when discharge lost seems disproportionally high. This may be due to low groundwater levels causing a high gradient between the river and water table which may have allowed more leakage.

Figure 27 (page 108) is a plot of the discharge lost from the river as a percent of the Clark Fork River discharge at the east end of the valley. With considerable variation, average discharge lost is 13.7 % of the Clark Fork River discharge. Note that the same 3 anomalies (late April, July and August) are present. This figure indicates that a simple river stage versus river leakage relationship is probably inappropriate for the Clark Fork River for the three mile reach.

Water chemistry results show a strong similarity between the inorganic chemistry of the Clark Fork River and the groundwater. Figure 11 (page 78) is a map of stiff diagrams representing gross ionic chemistry at both surface and groundwater sampling locations. Groundwater in the study area is very similar to Clark Fork River water. However, it is dissimilar to Bitterroot River water and water in the Rattlesnake Creek. These data

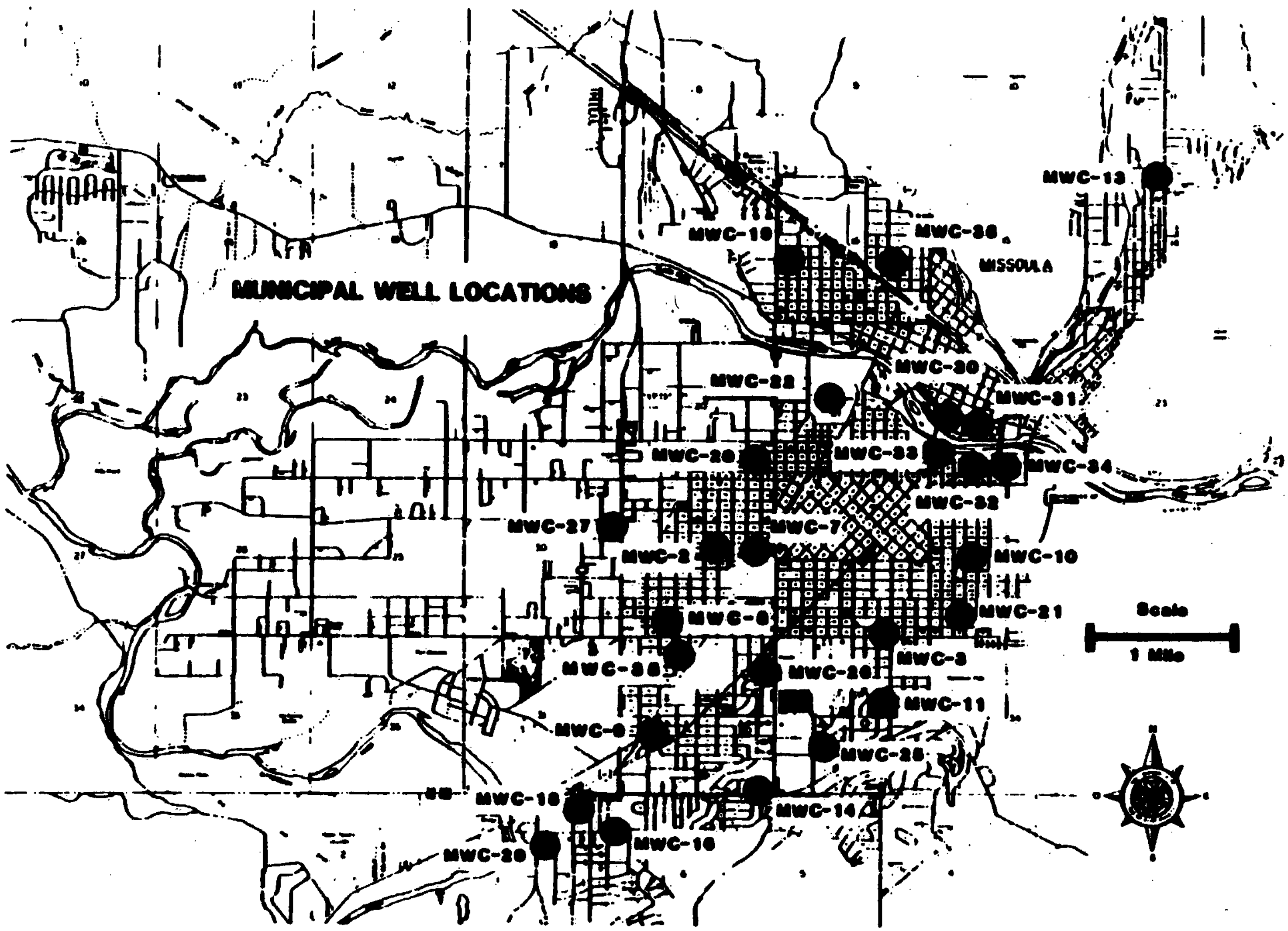

MUNICIPAL WELL LOCATIONS
MISSOULA
MWC-13
MWC-36
MWC-19
MWC-30
MWC-22
MWC-31
MWC-20
MWC-33
MWC-34
MWC-32
MWC-27
MWC-7
MWC-2
MWC-10
MWC-8
MWC-21
MWC-35
MWC-3
MWC-26
MWC-11
MWC-9
MWC-25
MWC-18
MWC-14
MWC-16
MWC-29
Scale
1 Mile

FIGURE 30

support potentiometric maps showing groundwater moving away from the Clark Fork River.

Potentiometric maps (Figures 23 - 25, pages 103-105) show that the Clark Fork River is perched above the adjacent water table and provides water to the aquifer. Due to a high hydraulic conductivity the gradient between the river and water table is steep. On May 5, 1986 the water table gradient was 0.36 in 62 feet from the river to well MV-34 172 ft away. Elsewhere in the valley the gradient is 0.0009. The potentiometric surface on February 28, 1986, at lowest groundwater levels during the study, had shifted toward the Clark Fork River from the position on August 22, 1985. The most profound shift was nearest the Clark Fork River. This suggests a reduction in recharge rates from the river. The seasonal shift in the potentiometric surface indicates that the groundwater system seems to react to variations in river recharge rates.

XI. PETITION AREAS

Executive Summary

This streamflow source area is defined as the "upstream headwaters of losing streams that flow into the recharge area." For the Missoula Aquifer, this area consists of two parts: 1) the area on the north side of the valley between the designated area and the watershed divide; and 2) the watershed of the Clark Fork river upstream from the canyon at the mouth of the Missoula Valley.

The designated area is defined as the "surface area above the aquifer and its recharge areas." The designated area for the Missoula Aquifer includes the areas of recharge from influent streams, as well as those areas in the north and east foothills that provide recharge to the aquifer through lateral inflow.

The project review area is defined as the "area within which Federal financially assisted projects will be reviewed, which includes the designated area and all or a portion of the streamflow source area." For the Missoula Aquifer, this area has been defined as all of the designated area and a portion of the streamflow source area within a fifteen mile radius of Missoula.

A. Streamflow Source Area

Because most of the streams entering the Missoula Valley have influent stretches that provide direct recharge to the Missoula Aquifer, surface water quality in these streams is very important. Section X describes and quantifies Aquifer recharge from influent streams.

The streamflow source area is defined as the "upstream headwaters of losing streams that flow into the recharge area." For the Missoula Aquifer, the streamflow source area is composed of two major parts: 1) the area on the North side of the valley between the designated area and the watershed divide. This area includes the headwaters of Rattlesnake Creek, Grant Creek, La Valle Creek, Butler Creek and other small creeks entering the valley from the North; and 2) the watershed of the Clark Fork River upstream from Hellgate Canyon. (See Figure 28, page 113).

Theoretically, any contaminant introduced into a surface water within the streamflow source could enter the Aquifer with recharge water and negatively affect aquifer water quality. An example of the transport of pollutants over the entire distance of the streamflow source area can be seen in the Milltown Reservoir, just east of Missoula where heavy metals have migrated with sediments in the Clark Fork River from near Butte and Anaconda, 120 miles away. The Milltown Dam has acted as an effective barrier to some types of contaminants, but probably would do little to help prevent dissolved contaminants from reaching the Aquifer.

The area along the Clark Fork River upstream from Missoula to near the drainage divide at Butte has historically been associated with surface water pollution. Mining and smelting of copper, silver and gold, livestock production, agricultural practices, timber production, and waste disposal, have all severely impacted the Clark Fork River water quality over the years. The Clark Fork could not support aquatic life until well into the era of water quality regulation. Reports of the river running red with heavy metal contaminated sediments were common prior to the 1960's.

Currently, 5 Superfund sites with 51 operable units are located along the Clark Fork River upstream from Missoula. For these reasons, activities in the Clark Fork River streamflow source area are of major concern. The streamflow source area of the influent streams on the north side of the valley are generally of much less concern than the Clark Fork source area because of the relatively small recharge contribution from smaller influent streams. The developed portions of the upper Rattlesnake drainage and Grant Creek drainage outside the designated area have potential to impact aquifer water quality. The majority of the area between the designated area and the watershed divide is public land managed by the U.S. Forest Service and the upper Rattlesnake drainage is a designated wilderness area (see Figure 28, page 113).

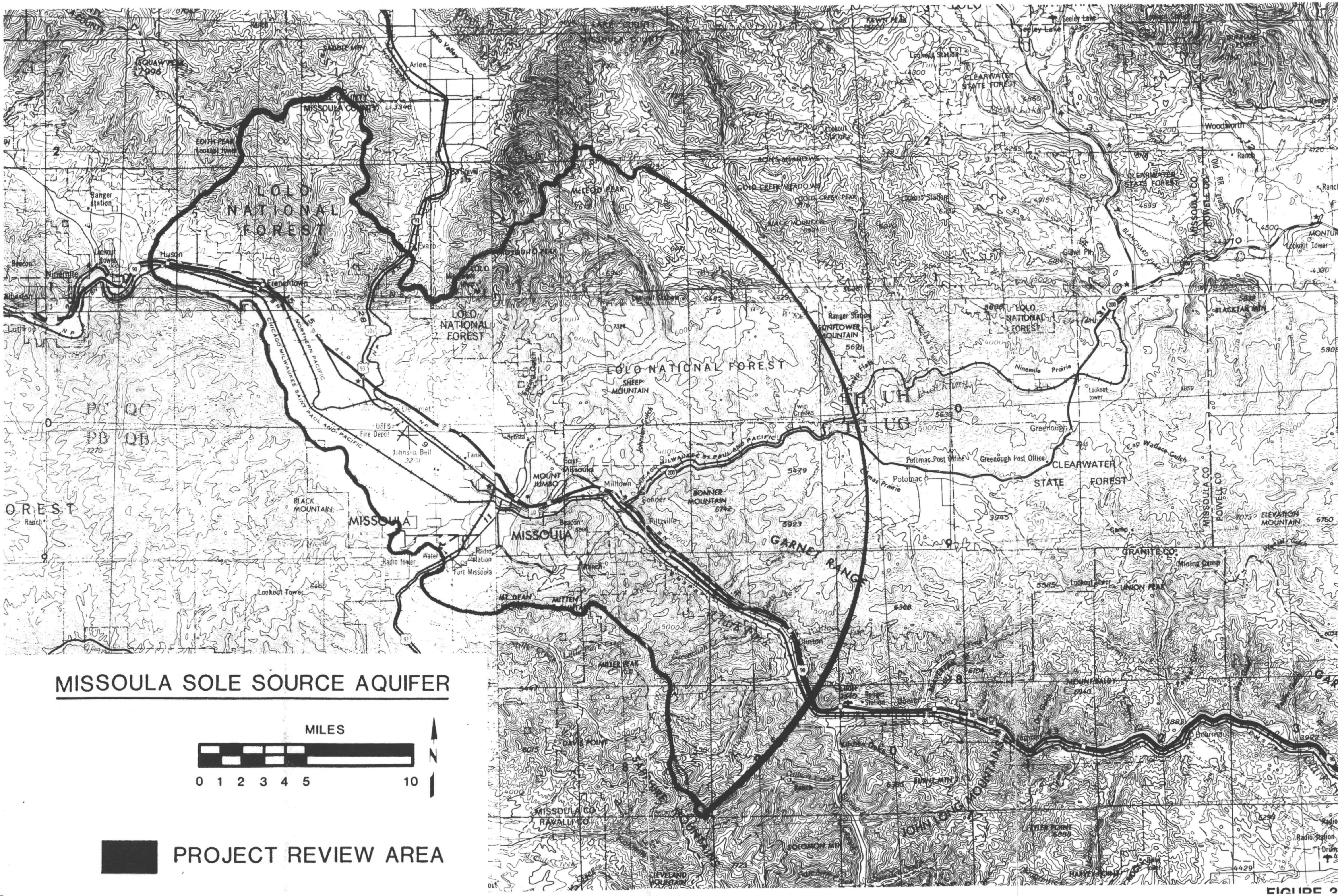
B. Designated Area

The designated area is defined as the "surface area above the Aquifer and its recharge areas." The sources of recharge to the Aquifer were discussed in detail in Section X. The designated area for the Missoula Aquifer is shown in Figure 2 (page 7). The designated area includes the areas of recharge from influent streams, as well as those areas in the north and east foothills that provide recharge to the Aquifer through lateral inflow.

C. Project Review Area

The Project Review area is defined as the "area within Federal financially-assisted projects will be reviewed, which includes the designated area and all or a portion of the streamflow source area." For the Missoula Aquifer, this area has been defined as all of the designated area and the portion of the streamflow source area within a 15 mile radius of Missoula (see Figure 31).

This represents the area in which major development projects are most likely to have an impact on Missoula Aquifer water quality. One area of concern not included in the proposed project



MISSOULA SOLE SOURCE AQUIFER

review area is the portion of the Clark Fork River streamflow source area further upstream of the proposed project review area. Including this area in the project review area is an alternative to the current proposal.

The proposed boundary was located near the Missoula County Line because it coincides with the petitioner's administrative authority and because, in the assessment of Missoula City-County Health Department staff, there is a decreasing gradient of the potential impact to the aquifer from surface water contamination in the upstream direction.

In addition, the streamflow source area upstream of Missoula encompasses nearly 7,200 square miles and it may not be realistic or practical to ask EPA to review projects within the entire streamflow source area.

APPENDIX A
CHEMICAL ANALYSIS OF COMMUNITY WATER SUPPLIES

APPENDIX A
CHEMICAL CONSTITUENTS OF COMMUNITY WELLS
(MG/L except PH)

SAMPLING SITE	WATER SUPPLY NAME							
	PH	CA	C03	CL	NA	FE	PB	AS
	TDS	MG	HC03	F	K	SE	MN	AG
	NO3-N	HARD	ALK	S04	BA	CD	HG	CR
GLESSNER TR. CRT	7.8	73			6.0	<.01	<.005	.004
11/04/85 #405		12	165	.1		<.002	<.005	<.01
	.9	234	135	9.0	.3	.001	<.0002	<.005
SORREL SPRINGS	8.0	36			8.0	<.01	<.005	.004
03/25/86 #518		9	163	.1		<.002	<.005	<.01
	1.1	133	134	5.0	.2	<.001	<.0002	<.005
SUNSET WEST-MSLA.	7.6	20			9.0	<.01	<.005	<.001
02/17/87 #1857		7	102	.2		<.002	<.005	<.01
	.9	80	84	6.0	.1	<.001	<.0002	<.005
VALLEY VIEW TR. CRT.	7.1	66			20.0	<.01	<.005	.004
FRENCHTOWN		24	307	.2		<.002	<.005	<.01
11/04/85 #404	.6	266	252	38.0	.3	<.001	<.0002	<.005
BIRCHWOOD DEPLEXES	7.6	51			6.0	.26	.005	<.005
10/28/85 #2537		12	189	.1		<.002	.006	<.01
	.7	179	155	22.0	.2	<.001	<.0002	<.005
BUENA VISTA TR. CRT.	7.0	8			1.0	<.01	<.005	<.001
03/05/86 #378		3	52	<.1		<.002	<.005	<.01
	.1	36	43	2.0	.0	<.001	<.0002	<.005
COUNTRYSIDE CRT.	7.6	59			11.0	<.01	<.005	<.001
10/30/85 #376		17	235	<.1		<.002	<.005	<.01
	1.9	223	193	11.0	.6	<.001	<.0002	<.005
ECONOMY WEST MOTEL	7.9	45			5.0	<.01	<.005	<.001
01/07/86 #870		12	171	<.1		<.002	<.005	<.01
	1.4	164	140	12.0	.3	<.001	<.0002	<.005
ELMAR ESTATES	8.3	51			7.0	<.02	<.005	<.001
05/ /86 #517		16		<.1		<.002	<.005	<.01
	1.2	195	160	19.0	.4	.002	<.0002	<.005
ELMAR TRAILER CRT.	7.0	11			2.0	<.01	<.005	<.001
10/30/85 #2517		4	71	<.1		<.002	<.005	<.01
	.1	47	58	2.0	.0	.002	<.0002	<.005
FUTURA PARK	7.9	43			6.0	<.01	<.005	<.001
03/03/86 #374		17	211	<.1		<.002	<.005	<.01
	.5	181	173	6.0	.1	<.001	<.0002	<.00-

FORT MISSOULA	7.5	58		5.0	8.0	<.10	.001	<.005
08/12/85 #3159	384.0	17	266	.1		<.001	<.03	<.02
	1.4	216	218	23.0	.2	.000	<.0002	<.025
WESTERN WATER CO.	7.7	51			8.0	<.01	<.005	<.001
MILLER CREEK		14	201	<.1		<.002	<.005	<.01
02/27/86 #293	1.5	191	165	16.0	.3	<.001	<.0002	<.005
GOODAN-KEIL ESTATES	7.8	38			13.0	<.01	<.005	<.001
02/13/86 #2393		13	185	.2		<.002	<.005	.03
	.8	152	152	6.0	.1	<.001	<.0002	<.005
GRASS VALLEY TR. CRT.	7.9	52			12.0		<.005	<.002
03/20/84 #436			235	<.1		<.002		<.01
	2.1		193		.6	<.001	<.0002	<.005
GREENFIELD TR. CRT.	8.0	54			7.0	<.01	<.005	<.001
03/11/86 #373		15	198	.1		<.002	<.005	<.01
	1.4	199	162	17.0	.4	<.001	<.0002	<.005
HELLGATE TR. CRT.	7.7	48			5.0	<.01	<.005	<.001
10/25/85 #2635		12	184	<.1		<.002	<.005	<.01
	1.2	173	151	13.0	.4	<.001	<.0002	<.005
HIDDEN HEIGHTS	7.6	36			3.0	<.01	<.005	.001
04/21/86 #2120		11	148	<.1		<.002	<.005	<.01
	.2	139	121	2.0	.3	<.001	<.0002	<.005
HOLLYWOOD TR. CRT.	7.6	53			6.0	<.01	<.05	<.001
02/10/86 #454		12	193	<.1		<.002	<.005	<.01
	1.3	186	158	9.0	.3	<.001	<.0002	<.005
HOWARD HORTON DUPLEX	7.7	41			12.0		<.005	<.001
04/02/84 #2634			192	.2		<.002		<.01
	4.7		157		.5	<.001	<.0002	<.005
TWITE DUPLEXES	7.8	51			7.0	<.01	<.005	<.001
2727 W. CENTRAL		13	185	.1		<.002	<.005	<.01
03/31/86 #829	.0	183	152	21.0	.2	.001	<.0002	<.005
TWITE DUPLEXES	7.5	51			6.0	<.01	<.005	<.001
WYOMING		12	185	.1		<.002	<.005	<.01
10/28/85 #2540	.7	181	152	24.0	.2	<.001	<.0002	<.005
TWITE DUPLEXES	7.6	51			6.0	.01	<.005	<.001
SO. 7TH ST.		14	189	.2		<.002	<.005	<.01
04/01/87 #2541	.8	187	155	21.0	.2	<.001	<.0002	<.005
MSLA. VILLAGE WEST	7.4	29			14.0	.18	<.005	.001
03/20/87 #3012		9	152	.3		<.002	<.005	<.01
	.5	113	125	7.0	.0	<.001	<.0002	<.005

MOBILE CITY TR. CRT.	7.7	50			6.0	.03	<.005	<.001
01/27/86 #646		13	185	.1		<.002	<.005	<.01
	.4	181	152	20.0	.2	<.001	<.0002	<.005
MOUNTAIN WATER CO.	7.7	50			9.0	.01	<.005	<.001
FARVIEW SYSTEM		18	217	.1		<.002	<.005	<.01
03/16/87 #294	1.5	204	178	18.0	.3	<.001	<.0002	<.005
NORTH DAVIS DUPLEX	7.8	48			7.0		<.005	<.001
03/14/84 #2121			185	.4		<.002		.01
	.4		152		.2	<.001	<.0002	<.005
RAMER WATER SUPPLY	7.5	48			6.0	.02	<.005	<.001
01/27/86 #575		12	171	.1		<.002	<.005	<.01
	.7	171	140	18.0	.2	<.001	<.0002	<.005
TARGET RANGE TR. CRT.	7.9	46			7.0		<.005	.001
03/19/84 #367			192	.1		<.002		<.01
	.9		157		.2	<.001	<.0002	<.005
LONG MACHINERY	8.1	49			6.0	<.01	<.005	<.001
SID 459 VALLEY WEST		13	178	<.1		<.002	<.005	<.01
03/26/86 #2580	1.5	178	146	14.0	.3	<.001	<.0002	.006
WAYSIDE MANOR	7.7	33			4.0	<.01	<.005	<.001
01/29/86 #380		7	122	<.1		<.002	<.005	<.01
	1.6	115	100	3.0	.2	<.001	<.0002	<.005
WESTVIEW PARK	7.8	44			6.0	<.01	<.005	<.001
03/05/86 #437		19	222	<.1		<.002	<.005	<.01
	.5	192	182	7.0	.1	<.001	<.0002	<.005
Numerical	7.7	45.1	---	---	7.2	<.03	<.005	<.0015
Averages	---	13.2	182	<.13	---	-----	<.002	<.01
	1.06	180	150	13.3	.31	<.001	<.0002	<.006

APPENDIX B
CENSUS DATA

Two sources were used for estimating the population and average household income in the aquifer service area. U.S. Census Data for 1980 provided a breakdown of Missoula County by census tract, enumeration district, and block group to develop an accurate estimate of the aquifer service area population. The population by census tract and source of water is depicted in Table B-1.

The 1980 census is an accurate representation of the current population as data from the Bureau of Business and Economic Research (BBER) shows little change in the county population from 1980 to 1986.

BBER has also provided estimates of per capita income and average household size based upon Department of Commerce data. For 1984 per capita income of Missoula County residents was $10,579 and there was an average of 2.5 people per household. Average household income for 1984 was $26,447.50. These values are expressed in tables B-2 and B-3.

POPULATION MISSOULA COUNTY (1980)	76,016
POPULATION CITY OF MISSOULA (1980)	33,388
POPULATION MISSOULA AQUIFER SERVICE AREA	60,282

PER CAPITA INCOME MISSOULA COUNTY	$10,579.00
AVERAGE HOUSEHOLD SIZE	2.5
PER HOUSEHOLD INCOME MISSOULA COUNTY	$26,447.50

TABLE B-1

MISSOULA AQUIFER SERVICE AREA
CENSUS TRACT POPULATION

CENSUS TRACT	POPULATION	WITHIN MSLA CITY LIMITS	OUTSIDE MSLA CITY LIMITS	SERVED BY MWC UTIL	SERVED BY CFWC UTIL	INDIVIDUAL WELL/SYSTEM	MISSOULA AQUIFER	OTHER SRC
1	4904	1388	3516	4832	-	72	4832	72
2.01	4752	4737	15	3832	-	920	4752	-
2.02	3563	43	3520	-	-	3563	3563	-
3	2094	2094	-	2094	-	-	-	-
4	1755	-	1755	-	-	1755	2	1753
5	1853	1853	-	1853	-	-	1853	-
6	4899	3905	994	4899	-	-	4899	-
7	2415	2276	139	2304	-	111	2415	-
8	4440	1951	2489	3330	-	1110	4440	-
9	5817	369	5448	1168	-	4649	5466	351
10	4340	1178	3162	4171	-	169	4340	-
11	3040	3040	-	3040	-	-	3040	-
12	4496	4496	-	4496	-	-	4496	-
13	12,100	6058	6042	8592	2329	1179	11,257	843*
14	5008	-	5008	144	-	4864	480	4528
15	4871	-	4871	-	-	4871	-	4871
16	3665	-	3665	-	-	3665	2353	1312
17	2004	-	2004	-	-	2004	-	2004
TOTALS	76,016	33,388	42,628	44,755	2329	28,932	60,282	15,734

*approximately 150 people lie within the aquifer service area within this census tract, yet use other aquifers (primarily the Renova Equilavent) for a water supply.

Source: U.S. Census, 1980, Census Tract Data, Missoula County, Montana

TABLE B-2

Households by Type
Missoula County
1980-1986

	1980	1981	1982	1983	1984	1985	1986
Total households (thousands of households)	27.6	28.8	28.8	29.3	29.7	30.2	30.7
Family households	18.9	19.7	19.8	20.1	20.5	21.0	21.5
Married couples	16.1	16.8	16.8	17.1	17.4	17.8	18.2
One spouse absent	2.8	2.9	3.0	3.0	3.1	3.2	3.3
Nonfamily households	8.7	9.1	9.0	9.1	9.2	9.2	9.3
Single person	6.2	6.5	6.5	6.6	6.7	6.8	6.9
Unrelated individuals	2.5	2.6	2.6	2.6	2.5	2.5	2.4
Population in households (thousands of persons)	73.3	73.6	73.6	73.7	74.4	75.4	75.8
Average household size (persons per household)	2.7	2.6	2.6	2.5	2.5	2.5	2.5

Source: University of Montana, Bureau of Business and Economic Research (August 1987).

Notes: Totals may not add due to rounding. These estimates must be interpreted cautiously. Montana counties are relatively small, and one or two events may have a significant impact on overall trends. Errors in data compilation may also affect the reliability of these estimates. In general, the estimates for total households are more reliable than the estimate for each type of household.

TABLE B-3

Total Personal Income by Major Component
Missoula County
1977-1984

(Thousands of Dollars)

	1977	1978	1979	1980	1981	1982	1983	1984
Total personal income	445,738	516,353	579,476	622,363	646,676	685,624	737,307	808,735
Population(persons)	71,000	72,200	74,100	76,700	76,400	75,200	75,400	76,500
Per capita personal income (dollars)	**6,281**	**7,149**	**7,821**	**8,117**	**8,463**	**9,114**	**9,774**	**10,579**
Derivation of total personal income								
Total labor income	361,296	426,245	471,710	494,628	484,720	496,239	557,912	616,590
Less: Social Security contributions	23,119	27,533	32,117	34,193	36,116	37,447	42,816	48,114
Plus: adjustment for residence	-19,651	-27,402	-33,383	-35,322	-32,060	-32,344	-36,976	-40,302
Equals: labor income by place of res.	318,526	371,310	406,210	425,113	416,544	426,448	478,120	528,174
Plus: dividends, interest, and rent	64,620	76,967	94,928	103,606	124,239	143,242	135,129	150,345
Plus: transfer payments	62,592	68,076	78,338	93,644	105,893	115,934	124,058	130,216
Labor income								
Farm	504	2,451	2,276	2,527	2,625	2,314	2,068	2,409
Nonfarm	360,792	423,794	469,434	492,101	482,095	493,925	555,844	614,181
Ag. services, forestry, fisheries	940	876	751	700	1,618	2,325	2,833	2,274
Mining	330	400	420	1,111	1,001	- 59	1,007	2,433
Construction	36,364	44,295	51,392	51,539	27,645	25,142	35,223	42,865
Manufacturing	67,009	83,711	93,390	92,243	95,357	91,199	108,448	114,970
Transportation and public utilities	39,634	45,506	52,369	55,379	55,557	60,362	59,263	63,355
Wholesale trade	22,690	25,939	28,031	30,957	32,147	28,011	28,650	30,305
Retail trade	44,518	53,364	58,309	58,267	59,654	61,878	68,513	77,597
Finance, insurance, and real estate	17,122	20,908	22,306	23,203	19,726	20,444	23,212	26,588
Services	57,993	67,429	71,970	78,735	83,811	89,249	106,105	125,306
Government and government enterprises	74,192	81,366	90,496	99,967	105,579	115,374	122,590	128,488
Federal, civilian	24,538	26,866	30,032	32,233	34,656	34,824	35,715	36,331
Federal, military	1,263	1,381	1,456	1,663	1,609	1,795	2,214	2,291
State and local	48,391	53,119	59,008	66,071	69,314	78,755	84,661	89,866

Source: U.S. Department of Commerce, Bureau of Economic Analysis, Regional Economic Information System.

Note: (D) Not shown to avoid disclosure of confidential information. Estimates are included in totals.
(L) Less than $50,000. Estimates are included in totals.

April 1986

APPENDIX C

WATER USE AND PRODUCTION

Use of drinking water in the Missoula basin may originate from three distinct sources. The largest supplier of drinking water is Mountain Water Co., a utility providing water service to an area roughly defined by the city limits of Missoula. MWC serves a population of nearly 45,000 and in addition has over 1300 commercial/industrial customers. Clark Fork Water Co. represents a much smaller private water utility providing service to primarily residential customers. They serve an estimated population of 2300. The remaining aquifer service area is reliant upon individual wells or small community water systems utilizing ground water from the Missoula Aquifer. The population using this distinct source numbers about 13,000 and includes residences as well as commercial and industrial users.

The following production tables show MWC's production by month and the number of customers for each year. Seasonal fluctuations and annual variations in water production demonstrate the variability of use related to climate. Prior to 1983 these values expressed both ground water and Rattlesnake surface water production. After July of 1983 the source is entirely from the Missoula Aquifer ground water supply.

TABLE C-1
Mountain Water Co. Production

PRODUCTION - CLIMATE & CUSTOMER COUNT COMPARISON

	1972	1973	1974	1975	1976
CUSTOMER COUNT	13986	14154	14413	14794	15373

	1972 PRODUCTION (x10(6)GAL)	1972 PRECIP.	1972 AVG. TEMP. (oF)	1973 PRODUCTION (x10(6)GAL)	1973 PRECIP.	1973 AVG. TEMP. (oF)	1974 PRODUCTIO (x10(6)GAL)	1974 PRECIP.	1974 AVG. TEMP. (oF)	1975 PRODUCTION (x10(6)GAL)	1975 PRECIP.	1975 AVG. TEMP. (oF)	1976 PRODUCTION (x10(6)GAL)	1976 PRECIP.	1976 AVG. TEMP. (oF)
JAN	523.00	2.04	20.6	693.79	0.44	21.5	618.48	2.07	21.2	510.53	2.03	22.7	532.09	0.90	28.0
FEB	586.95	1.82	28.1	680.53	0.17	30.9	620.15	0.68	31.9	531.59	1.77	22.4	525.81	1.04	31.7
MARCH	567.11	1.62	40.6	611.31	0.23	39.0	560.91	1.26	35.4	680.48	0.74	33.0	479.29	0.40	34.8
APRIL	638.49	0.96	42.6	713.18	0.33	43.1	640.48	0.61	45.9	729.67	1.01	39.3	615.50	0.94	46.3
MAY	691.38	0.69	54.2	881.51	0.54	53.2	694.96	0.44	48.5	698.14	1.35	49.2	798.31	0.79	55.0
JUNE	928.34	1.37	62.0	942.32	1.57	60.0	867.08	1.36	65.0	938.81	2.02	55.4	1007.94	1.52	56.8
JULY	979.32	0.64	64.9	1178.84	0.09	69.6	863.45	1.03	68.1	981.08	1.51	71.8	1017.37	1.20	66.8
AUGUST	1107.16	0.24	66.4	1308.20	0.31	67.4	883.50	1.18	65.1	1043.92	2.03	62.1	922.81	0.88	63.2
SEPT	944.76	1.66	51.4	675.45	0.60	56.5	668.83	0.70	57.1	574.11	0.51	56.1	880.23	0.58	57.4
OCT	679.38	0.78	42.5	447.00	0.60	45.3	564.98	0.25	46.3	527.31	3.51	43.6	757.92	0.33	43.9
NOV	645.70	0.41	33.6	454.82	2.51	30.2	495.12	0.50	34.7	525.96	1.15	30.4	689.71	0.22	32.3
DEC	639.69	1.46	19.3	582.65	1.62	30.3	502.44	0.68	27.8	516.48	0.85	25.7	764.69	0.25	24.4
TOTAL	8931.28	13.69	526.2	9169.60	9.01	547.0	7980.38	10.76	547.0	8258.08	18.48	511.7	8991.67	9.05	540.6
AVERAGE	744.27	1.14	43.9	764.13	0.75	45.6	665.03	0.90	45.6	688.17	1.54	42.6	749.31	0.75	45.1

TABLE C-1 (cont'd)

PRODUCTION - CLIMATE & CUSTOMER COUNT COMPARISON

	1977			1978			1979			1980			1981		
CUSTOMER COUNT	15282			15688			15871			16207			16142		
	PRODUCTION (x10(6)GAL)	PRICIP.	AVG. TEMP. (oF)	PRODUCTION (x10(6)GAL)	PRICIP.	AVG. TEMP. (oF)	PRODUCTION (x10(6)GAL)	PRICIP.	AVG. TEMP. (oF)	PRODUCTION (x10(6)GAL)	PRICIP.	AVG. TEMP. (oF)	PRODUCTION (x10(6)GAL)	PRICIP.	AVG. TEMP. (oF)
JAN	801.62	0.66	18.6	706.17	1.15	24.2	755.21	1.25	5.6	628.87	1.80	16.3	540.71	0.16	29.5
FEB	811.47	0.18	31.9	681.80	0.66	27.3	846.15	1.04	25.5	589.17	0.60	29.6	509.42	0.77	31.4
MARCH	558.93	0.98	34.2	675.09	0.67	39.8	749.90	1.22	35.9	615.53	0.88	34.6	576.08	1.43	40.0
APRIL	637.16	0.08	46.9	720.23	1.08	46.1	709.91	1.04	43.9	673.72	0.96	49.8	604.16	0.74	46.7
MAY	753.24	2.13	50.3	652.12	1.98	48.3	759.48	0.74	52.2	726.92	7.38	54.7	650.15	4.19	53.4
JUNE	802.98	0.66	63.4	820.56	0.77	59.6	1011.04	0.67	62.3	626.89	2.04	58.6	582.49	2.70	57.5
JULY	1057.72	0.72	65.8	853.90	0.57	65.3	1105.33	0.77	69.2	878.58	1.58	65.5	966.13	1.07	65.0
AUGUST	1125.66	1.28	67.6	1074.44	1.11	63.5	1144.47	1.31	69.1	992.64	0.62	61.8	1038.43	1.61	69.4
SEPT	866.80	1.67	54.6	710.05	1.78	55.1	843.43	0.05	61.4	663.34	0.77	57.0	651.04	1.01	56.7
OCT	662.45	0.72	44.2	760.12	0.01	45.3	779.33	0.97	48.1	620.88	0.75	45.3	516.86	0.62	41.7
NOV	653.04	1.02	31.3	684.28	1.00	26.7	640.04	0.50	27.2	545.05	0.63	34.2	303.19	1.07	32.7
DEC	668.59	2.88	24.5	632.40	0.99	15.9	590.32	0.81	31.2	564.06	1.34	30.5	446.71	1.98	24.0
TOTAL	9399.66	12.98	533.3	8971.16	11.77	517.1	9934.61	10.37	531.6	8125.65	19.35	537.9	7385.37	17.35	548.0
AVERAGE	783.31	1.08	44.4	747.60	0.98	43.1	827.88	0.86	44.3	677.14	1.61	44.8	615.45	1.45	45.7

TABLE C-1 (cont'd)

PRODUCTION - CLIMATE & CUSTOMER COUNT COMPARISON

	1982			1983			1984			1985			1986		
CUSTOMER COUNT	16073			16100			16202			16238			16331		
	PRODUCTION (x10(6)GAL)	PRICIP.	AVG. TEMP. (oF)	PRODUCTION (x10(6)GAL)	PRICIP.	AVG. TEMP. (oF)	PRODUCTIO (x10(6)GAL)	PRICIP.	AVG. TEMP. (oF)	PRODUCTION (x10(6)GAL)	PRICIP.	AVG. TEMP. (oF)	PRODUCTION (x10(6)GAL)	PRICIP.	AVG. TEMP. (oF)
JAN	505.57	2.07	21.2	503.90	0.62	30.0	699.35	0.86	25.4	701.12	0.19	19.2	656.18	0.93	26.0
FEB	523.94	1.31	22.7	441.62	0.95	34.5	664.30	0.44	32.1	634.76	0.70	23.7	596.43	2.18	28.6
MARCH	516.52	1.52	38.3	476.51	1.10	39.9	707.77	1.32	37.7	718.14	0.44	36.2	673.77	0.54	41.7
APRIL	520.97	1.34	41.6	563.69	0.72	44.6	706.45	2.04	43.8	739.89	0.55	47.7	693.29	0.51	43.5
MAY	706.82	2.03	51.0	735.18	2.65	51.8	753.22	2.02	49.3	988.28	1.57	55.4	867.58	1.69	54.3
JUNE	797.25	1.83	63.0	866.44	2.26	58.6	841.83	1.47	56.8	1087.28	0.38	62.0	1115.73	2.66	65.5
JULY	777.81	0.94	64.6	763.68	2.44	62.1	1328.28	0.38	67.2	1512.83	0.09	74.8	1099.16	0.84	62.5
AUGUST	947.44	0.38	66.6	889.69	1.27	68.9	1124.75	1.47	68.4	859.17	3.29	62.2	1254.51	1.68	69.5
SEPT	654.89	2.09	56.2	701.64	1.37	51.1	776.35	0.79	52.8	690.13	3.60	50.5	703.15	3.54	53.0
OCT	528.12	0.43	45.0	649.63	0.37	43.8	718.47	0.96	42.5	648.45	0.80	40.3	651.57	0.44	44.7
NOV	455.14	0.37	29.0	608.71	1.17	34.3	649.83	0.89	33.9	621.48	0.51	21.7	588.91	1.07	31.7
DEC	512.19	1.07	22.7	644.84	1.79	11.8	691.90	0.66	20.1	644.43	0.38	14.7	585.14	0.50	21.4
TOTAL	7446.66	15.38	521.9	7845.53	16.71	531.4	9662.50	13.30	530.0	9845.96	12.50	508.4	9485.42	16.58	542.4
AVERAGE	620.56	1.28	43.5	653.79	1.39	44.3	805.21	1.11	44.2	820.50	1.04	42.4	790.45	1.38	45.2

027

TABLE C-1 (cont'd)

1987

CUSTOMER COUNT

	PRODUCTION (x10(6)GAL)	PRICIP.	AVG. TEMP. (oF)
JAN	598.37	0.28	20.5
FEB	550.35	0.37	30.6
MARCH	617.85	1.23	38.0
APRIL	683.71	0.41	50.1
MAY	821.28	1.31	55.9
JUNE	863.34	1.53	62.9
JULY	975.33	2.47	64.7
AUGUST	952.31	1.05	62.2
SEPT	826.52	0.09	59.3
OCT			
NOV			
DEC			
TOTAL	6889.06	8.74	444.2
AVERAGE	765.45	0.97	49.4

APPENDIX D
MONTANA WATER QUALITY STANDARDS

16.20.615 SPECIFIC SURFACE WATER QUALITY STANDARDS --- GENERAL (1) Specific surface water quality standards, along with general provisions in ARM 16.20.631, protect the beneficial water uses set forth in the water-use descriptions for the following classifications of water.

(2) Standards for organisms of the coliform group are based on a minimum of five samples obtained during separate 24-hour periods during any consecutive 30-day period analyzed by the most probable number or equivalent membrane filter methods.(History: Sec. 75-5-301 MCA; IMP, Sec. 75-5-301 MCA; Eff. 12/31/72; AMD, 11/4/73; AMD, Eff. 9/5/74; AMD, 1980 MAR p. 2252, Eff. 8/1/80.)

16.20.616 A-CLOSED CLASSIFICATION (1) Waters classified A-Closed are suitable for drinking, culinary and food processing purposes after simple disinfection.

(2) Public access and activities such as livestock grazing and timber harvest are to be controlled by the utility owner under conditions prescribed and orders issued by the department.

(3) For waters classified A-Closed the following specific water quality standards shall not be violated by any person:

(a) The geometric mean number of organisms in the coliform group must not exceed 50 per 100 milliliters.

(b) Dissolved oxygen criteria are not applicable for the classification.

(c) No change from natural pH is allowed.

(d) No increase above naturally occurring turbidity is allowed.

(e) No increase above naturally occurring water temperature is allowed.

(f) No increases are allowed above naturally occurring concentrations of sediment, settleable solids, oils, or floating solids, which will or are likely to create a nuisance or render the waters harmful, detrimental, or injurious to public health, recreation, safety, welfare, livestock, wild animals, birds, fish, or other wildlife.

(g) No increase in true color is allowed.

(h) No increases in toxic or other deleterious substances, pesticides, or organic or inorganic materials, including heavy metals, above naturally occurring concentrations, are allowed.

(i) No increase in radioactivity above natural background levels is allowed. (History: Sec. 75-5-301 MCA; IMP, Sec. 75-5-301 MCA; Eff. 12/31/72; AMD, Eff. 11/4/73; AMD, Eff. 9/5/74; AMD, 1980 MAR p. 2252, Eff. 8/1/80.)

16.20.618 B-1 CLASSIFICATION (1) Waters classified B-1 are suitable for drinking, culinary and food processing purposes after conventional treatment; bathing, swimming, and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl, and furbearers; and agriculture and industrial water supply.

(2) For waters classified B-1, the following specific water quality standards shall not be violated by any person:

(a) During periods when the daily maximum water temperature is greater than 60° F, the geometric mean number of organisms in the fecal coliform group must not exceed 200 per 100 milliliters, nor are 10 percent of the total samples during any 30-day period to exceed 400 fecal coliforms per 100 milliliters.

(b) Dissolved oxygen concentration must not be reduced below 7.0 milligrams per liter.

(c) Induced variation of hydrogen ion concentration (pH) within the range of 6.5 to 8.5 must be less than 0.5 pH unit. Natural pH outside this range must be maintained without change. Natural pH above 7.0 must be maintained above 7.0.

(d) The maximum allowable increase above naturally occurring turbidity is 5 nephelometric turbidity units except as permitted in ARM 16.20.633.

(e) A 1° F maximum increase above naturally occurring water temperature is allowed within the range of 32° F to 65° F; within the naturally occurring range of 66° F to 66.5° F, no discharge is allowed which will cause the water temperature to exceed 67° F; and where naturally occurring water temperature is 66.5° F or greater, the maximum allowable increase in water temperature is 0.5° F. A 2° F per hour maximum decrease below naturally occurring water temperature is allowed when the water temperature is above 55° F, and a 2° F maximum decrease below naturally occurring water temperature is allowed within the range of 55° F to 32° F. This applies to all waters in the state classified B-1 except for the Prickly Pear Creek from McClellan Creek to the Montana Highway No. 433 crossing where a 2° F maximum increase above naturally occurring water temperature is allowed within the range of 32° F to 65° F; within the naturally occurring range of 65° F to 66.5° F, no discharge is allowed which will cause the water temperature to exceed 67° F; and where the naturally occurring water temperature is 66.5° F or greater, the maximum allowable increase in water temperature is 0.5° F.

(f) No increases are allowed above naturally occurring concentrations of sediment, settleable solids, oils, or floating solids, which will or are likely to create a nuisance or render the waters harmful, detrimental, or injurious to public health, recreation, safety, welfare, livestock, wild animals, birds, fish, or other wildlife.

(g) True color must not be increased more than 5 units above naturally occurring color.

(h) Concentrations of toxic or other deleterious substances which would remain in the water after conventional water treatment must not exceed the maximum contaminant levels set forth in the 1975 National Interim Primary Drinking Water Standards (40 CFR Part 141) or subsequent revisions or the 1979 National Secondary Drinking Water Standards (40 CFR Part 143) or subsequent revisions. The maximum allowable concentrations of toxics or deleterious substances also must not exceed acute or chronic problem levels as revealed by bioassay or other methods. The values listed in EPA Water Quality Criteria documents (Federal Register Vol. 45, No. 231, Friday, November 28, 1980, pages 79318 - 79379) shall be used as a guide to determine problem levels unless local conditions make these values inappropriate. In accordance with sections 75-5-306(1), MCA, it is not necessary that wastes be treated to a purer condition than the natural condition of the receiving water.

(3) The board hereby adopts and incorporates by reference "EPA Water Quality Criteria documents (Federal Register Vol. 45, No. 231, Friday, November 28, 1980, pages 79318 - 79379)", which set forth water quality criteria for toxic and other deleterious substances. Copies of this document may be obtained from the Water Quality Bureau, Department of Health and Environmental Sciences, Cogswell Building, Capital Station, Helena, Montana, 58620. (History: Sec. 75-5-301 MCA; IMP, Sec. 75-5-301 MCA; Eff. 12/31/72; AMD, Eff. 11/4/73; AMD, Eff. 9/5/74; AMD, 1980 MAR p. 2252, Eff. 8/1/80; AMD, 1982 MAR p. 1746, Eff. 10/1/82; AMD, 1984 MAR p. 1802, Eff. 12/14/84.)

APPENDIX E

WATER QUALITY DATA

The following table depicts the water quality of the groundwater system currently being used as a municipal water supply.

APPENDIX E

SURFACE WATER QUALITY

Source	Date	Ca	Mg	HCO3	CO3	PO4	NO3+ NO2	pH	Temp C	Hard	Alk	TSS	Cu	P	N	As	Zn	Amm. as N	VSS
Bitterroot @	12/10/86	20.9	4.8	92.7	0.0	<.001	.08	8.15	0.2	72	76	1.0	<.01	.005	<.1	<.001	<.005	<.01	0.6
McClay's Brdg	3/9/87	16.3	3.7	69.5	0.0	.012	.11	7.72	4.0	56	57	10.3	<.01	.026	.1	<.001	.005	<.01	2.5
13N 20W 26cbd	5/4/87	7.4	1.3	41.5	0.0	.012	.05	7.14	10.7	24	34	13.6	<.01	.022	.3	<.001	<.005	<.01	1.9
Clark Fork @	12/10/86	50.7	13.8	164.7	0.0	.037	.06	8.29	0.0	183	135	5.0	<.01	.048	.4	.005	.013	.22	1.3
Shuffields	3/9/87	40.7	11.0	129.3	0.0	.079	.13	8.01	2.2	147	106	32.4	.01	.14	.5	.006	.033	.06	5.6
13N 20W 24aad	5/19/87	24.1	7.1	98.8	0.0	.015	<.01	7.94	12.0	89	81	6.5	<.01	.030	.2	.001	.011	.03	1.6
Clark Fork @	12/10/86	50.7	13.9	164.7	0.0	.007	.06	8.29	0.0	184	135	5.3	.01	.014	<.1	.005	.017	.02	1.2
Above STP	3/9/87	41.9	11.2	128.1	0.0	.049	.12	8.05	1.8	151	105	34.3	.01	.10	.4	.006	.040	.23	5.9
13N 19W 18dda	5/19/87	23.9	7.1	98.8	0.0	.007	<.01	7.95	11.6	89	81	-	<.01	.016	.1	.001	.029	<.01	1.5
Clark Fork @	12/10/86	51.5	14.3	168.4	0.0	.014	.08	8.29	0.0	187	138	12.5	.02	.022	.1	.006	.041	.02	2.0
Blo Milltown	3/9/87	43.4	11.7	130.5	0.0	.038	.10	8.01	-	157	107	28.3	.02	.097	.3	.006	.042	.04	5.2
13N 18W 18cbc	5/19/87	25.5	7.7	103.7	0.0	.003	<.01	7.89	10.9	95	85	5.4	<.01	.017	.2	.002	.007	<.01	1.4
Blackfoot @	12/10/86	39.1	13.8	172	0.0	<.001	.01	8.3	-	154	141	1.9	<.01	.004	<.1	.001	<.005	<.01	0.7
USGS Gage Sta	3/9/87	31.8	10.8	129.3	0.0	.033	.04	7.98	0.0	124	106	1208	<.01	.078	.4	.001	.006	.10	3.3
13N 17W 9bdd	5/19/87	23.9	8.0	103.7	0.0	.002	<.01	8.01	11.0	93	85	6.5	<.01	.011	<.1	<.001	<.005	<.01	1.8

Source	Date	pH	HCO_3	SO_4	Cl	NO_3	PO_4	SiO_2	Ca	Mg	Na	K	TDS
Rattlesnake Cr.	8/9/78	7.6	22.7	1.0	0.4	0.022	0.026	6.9	3.4	1.6	1.4	0.4	37.8
Grant Creek	8/28/78	7.6	24.9	1.0	0.1	0.013	0.018	7.8	3.6	2.0	1.2	0.4	42.4
	6/21/78	7.4	15.5	1.0	0.5	0.010	0.017	3.9	2.2	1.2	0.8	0.4	46.1
Butler Creek	1/23/78	7.6	25.2	1.7	0.3	0.037	0.009	12.0	2.8	2.4	2.4	0.5	76.5
	5/17/78	8.1	136.9	2.2	0.4	0.020	0.014	10.4	16.8	15.1	4.2	0.8	188.4
	1/23/78	7.7	34.6	1.6	0.3	0.06	0.018	13.2	3.7	2.3	1.8	0.5	38.1
O'Brien Creek	11/23/77		173.0	3.6	0.5	0.006	0.011	14.5	28.0	16.3	3.9	1.5	243.3
Pattee Creek	1/16/78	8.0	53.0	5.1	3.4	0.009	0.074	25.5	7.2	4.8	6.0	1.9	106.9
	4/16/78	7.7	31.8	9.0	3.2	0.076	0.121	16.0	4.4	3.2	5.9	2.2	77.1
Miller Creek	8/10/78	8.3	123.5	5.7	0.6	0.063	0.042	16.3	21.1	11.1	3.3	1.4	186.7

Note: All values in milligrams/liter (mg/l) except for pH (standard units) and temperature (centigrade units)

Source: Montana Department of Health and Environmental Sciences, Water Quality Bureau, Helena, Montana

APPENDIX F

METHODS FOR DEVELOPING COSTS FOR ALTERNATIVES

Numerous sources have been utilized to develop an estimate of costs involved in providing an alternative water supply to the Missoula area. Gerald Lukasik, professional engineer from Mountain Water Co., has been helpful in providing many of the numbers concerning water treatment costs and water distribution costs. Reports by Sanderson, Stewart, and Gaston Engineering has helped support the cost estimates, along with the EPA publications "Estimating Water Treatment Costs" (EPA 600/2-79-162a) and "Managing Small Water Systems: A Cost Study" (EPA 600/2-79-147a). Steve Fry, project manager Painted Rocks Reservoir (MDNRC), and Patrick White, engineer James Montgomery Engineering, have contributed to the preparation of cost estimates. Comparisons were made, when possible, to projects that possess similar characteristics to developing a water supply for the Missoula area.

The economic feasibility of a project is determined by the breaking point of 0.6% of the average household income. If annual costs exceed this breaking point, the project will be deemed economically infeasible. Conversely, if costs for a proposed project falls below that value it will be considered a plausible alternative to the existing supply. Breaking point costs are expressed in two ways: total annual costs of proposed project, and unit costs of 1000 gallons of delivered water.

AVERAGE HOUSEHOLD INCOME, MISSOULA COUNTY	$ 26,447.50
0.6% OF AVE HOUSEHOLD INCOME	$ 158.69
HOUSEHOLDS IN AQUIFER SERVICE AREA	x 24,113 Homes
BREAKING POINT ANNUAL COSTS/PROJECT	$3,826,339.67

If a proposed project were to provide the existing demand for water, an average of 30 mgpd or 10,950 million gallons annually would be required.

DEMAND AQUIFER SERVICE AREA	10,950,000 thous gals
BREAKING POINT UNIT COSTS	$0.3494/1000 gals

Project costs are subdivided into capital investment costs and annual operating costs. Since capital costs are typically long range investments, an annualization factor of 0.1 was applied to develop annual payments of those costs.

Methods for providing estimates for individual components of a new water supply are outlined below. Included in Table F-1 are cost estimates of water production for Rattlesnake Creek prepared by Gerald Lukasik, MWC engineer.

ADMINISTRATIVE COSTS

MWC currently provides service to 75% of the Missoula basin's population. If another source of drinking water is required to replace the current ground water source it is assumed administration of the system would fall into MWC's hands. MWC's total operational costs for 1986 was $3.2 million with $30,000 being devoted to capital improvements on the well system. Operational and maintenance costs (O&M) of the well system was $686,735. The remaining $2,483,265 covers administration, management, customer service, etc. for the company and entire water system.

MWC 1986 OPERATIONAL COSTS	$3,200,000
CAPITAL IMPROVEMENTS	$ 30,000
O&M WELL FIELD	$ 686,735
TOTAL ADMINISTRATIVE & MANAGEMENT COSTS	$2,483,265

The cost is applied to all potential development schemes to account for management and administration of the water utility. Expanding the utility's distribution system may incur greater operational costs but these increases are not reflected in the estimates presented.

DISTRIBUTION IMPROVEMENTS

A good portion of the Missoula basin lack water transmission lines, as residents and businesses rely upon their own wells for providing drinking water. The provision of an alternative supply to the ground water would require extensive development of a distribution system to the unconnected areas of the basin. The new system would consist of an array of water distribution lines of varied sizes. Gerald Lukasik, MWC, developed a value for estimating the cost by figuring an average size of water main, eight inches, and estimating 150 feet of main would be required per household. Considering an average cost of $6000/household for the 5279 households in the unconnected areas of the basin, total capital costs for the project would equal $31,674,000.

AVE. WATER MAIN DIAMETER	8 in
AVE. LENGTH OF WATER MAIN/HOUSEHOLD	150 ft
TYP. COST INSTALLATION 8" MAIN	$40/ft
AVE. COST/HOUSEHOLD	$6000/Household
UNCONNECTED HOUSEHOLDS	5279 Households
CAPITAL INVESTMENTS DISTRIBUTION SYSTEM	$ 31,674,000

WELL FIELD DEVELOPMENT

Construction of an auxiliary well field would require the drilling of new wells, the provision of electricity to the site to handle pumping, and the construction of a transmission line to the Missoula area. The costs of developing these factors will depend upon geologic and site conditions. For this report previous well development in the Missoula aquifer will be compared to potential development in the Bitterroot Valley. The Stone Container Corp. has recently completed development of 18" diameter wells with the capacity of pumping 2000 gpm. Approximate costs for developing a single well was $200,000, including the provision of electricity to the site. It is assumed that development costs for a well in the Bitterroot Valley would be similar.

A site south of Lolo, MT would require approximately twelve miles of main to be constructed to bring the water into the Missoula area. Gerald Lukasik has estimated the cost of laying a 30" main is $100/ft. Numerous variables, such as the number of pumping stations, geologic conditions, and right of way agreements may cause this value to fluctuate, but is assumed to approximate real costs.

MISSOULA AREA WATER DEMAND	11 billion gals/yr
PEAK DAILY DEMAND	50 million gals/day
NUMBER WELLS TO MEET DEMAND (@ 2000 gpm)	18 wells
WELL DEVELOPMENT COSTS (2000 gpm)	$ 200,000/well
18 WELLS AT BITTERROOT SITE	$ 3,600,000
30" MAIN EMPLACEMENT	$ 100/ft
12 MILES OR 63,360 FEET	$ 6,336,000

RESERVOIR DEVELOPMENT

Construction costs of a reservoir will vary considerably depending upon the site. Other associated costs include structure replacement and proximity of appropriate construction material. An accurate estimate of reservoir development in an O'Brien Creek site would require a thorough investigation of conditions and obstacles to development. However, comparisons may be made to similar studies performed in the area. The Big Hole River drainage of southwestern Montana has been studied for reservoir development to augment irrigation water supplies. The Montana Department of Natural Resources and Conservation has studied several sites for reservoir development. The costs of developing a reservoir with the capacity of delivering between 25,000 to 35,000 acre-feet annually ranges from $27 to $109 per acre foot (af). The average cost is $ 59/af and includes total annual project costs for repayment, operation, and maintenance of the project in 1980 dollars. If this value were to hold for an O'Brien Creek site annual costs for a 30,000 af reservoir would reach $ 1,770,000.

WATER TREATMENT

Gerald Lukasik has estimated the costs for constructing a 50 mgpd conventional water treatment plant to be $0.30/gallon of daily designed capacity. Patrick White, an engineer with James Montgomery Engineers, has provided a similar comparison of treatment plant construction costs. He has estimated the costs to range from $0.22 to $0.40/gallon (average $0.32/gallon) for the daily designed capacity. Figures taken from "Estimating Water Treatment Costs" provides a similar value but for a smaller capacity plant. For a 40 mgpd conventional water treatment plant, total construction costs are expected to run $0.26/gallon. however this value may be low because it represents 1978 dollars.

For the purposes of this report a value of $0.30/gallon of daily designed capacity will be used for construction estimates. Total costs are expected to be $15,000,000.

Operational and maintenance (O&M) costs for water treatment will vary considerably depending upon the type of treatment required and chemicals used. This report uses O&M costs derived from a 40 mgpd conventional treatment plant described in "Estimating Water Treatment Costs". Annual costs for labor, electricity, fuel, maintenance material, and chemicals is estimated to be $876,440. A plant designed for the Missoula area would have an increased capacity of 50 mgpd. A factor of 1.25 was multiplied to O&M costs for the 40 mgpd plant to approximate the increased capacity. Annual O&M costs for such a plant is expected to be $1,095,550.

This value may be adjusted in two ways. Since the source is using 1978 dollars actual costs may be much higher. And economies of scale may prove the multiplication factor to be slightly less than as expressed on a linear scale. It is doubtful these two factors may cancel each other but neither are considered in the estimate.

CAPITAL CONSTRUCTION COSTS ($0.30/gal)	$15,000,000
ANNUALIZED CAPITAL (0.1 factor)	$ 1,500,000
TREATMENT O&M	$ 1,095,550
TOTAL ANNUAL COSTS	$ 2,595,550

APPENDIX G

SUMMARY OF CENOZOIC GEOLOGY

Four significant stratigraphic subdivisions are present in the Missoula Valley. They include the pre-Renova equivalent, the Renova equivalent, the Sixmile Creek equivalent and Quaternary lake silts, loess and alluvial gravels. The first three are separated by major unconformities.

The pre-Renova equivalent rests unconformably on pre-basin rocks near the faulted-boundaries of the Missoula and Bitterroot basins. Fields (1981) logged conglomerates in well MB-2 near Alberton, Montana drilled for the U.S. Department of Energy.

In this well, conglomerate underlies the Renova equivalent and appears to intertounge with basal Renova. Fields (1981) interprets the conglomerate facies as repeated mudflows and fanglomerates derived from the adjacent fault-bounded uplands. From comparison of other Department of Energy wells located near basin centers, he concludes that the formation is limited to basin margins.

The Renova Formation equivalent unconformably overlies pre-basin rocks or the pre-Renova Formation. It has an overall fine-grained aspect. It was deposited between late Eocene and middle early Miocene times. Kuenzi and Fields (1091) define the Renova as being greater than 70% fine grained and/or less than 30% coarse grained of which conglomerate is a minor component. Fields and others (1985) divide the Renova into two parts. The lower part characteristically has devitrified volcaniclastics, abundant lacustrine deposits and minor amounts of locally derived coarse clastics, arkose and air-fall ash. The lacustrine sediments include organic-rich, freshwater ashy shales and marls. Locally, coal is abundant. In addition, fossil plant remains of riparian foliage including alder and willow, and upland tree needles of <u>Metasquoia</u> are found (Wehrenberg, 1983). The upper part is dominated by large quantities of ash and mud. Within the montmorillonite mudstones and volcaniclastics scattered lenses of coarse clastics, arkose and conglomerate occur. Fossil floras are rare (Fields and others, 1985). In the Jefferson basin Kuenzi and Fields report up to 3500 feet of Renova sediments.

In the Missoula basin the Renova equivalent is intermittently exposed on the basin flanks and recorded in Department of Energy well MB-4 (Figure 17). In the O'Keefe Creek valley a railroad cut exposes the lower to middle part of the Renova. Expanded smectite clays with a "popcorn texture", seams of lignite, siltstones, mudstones and arkosic sandstones are present. Feldspars and micas in the sandstones indicate that the Bitterroot Dome to the south was breached by Oligocene time. Carbonized leaves and needles are well preserved in the mudstones. In Coal Creek canyon north of I-90 and the city of Missoula sanitary landfill, a 7 foot coal seam was mined until World War II. Fields (1981) states that the lignite represents an Oligocene age based on coincident occurrence with fossil flora at O'Keefe Creek. The coal seam and an up-section layer of tuff dip north 20. The Department of Energy drill hole is located 2 miles north of I-90 and east of Butler Creek road (NW SE NE Sec. 24, T.14N, R.20W). Fields (1981) reports the Renova equivalent occurring from 90 to 2700 feet. It includes carbonaceous siltstone and mudstone with numerous seams of lignite, arkosic sandstone, and poorly sorted pea gravel and cobble conglomerate. From 2800 to 2907 feet (total depth) a tectonic breccia is recorded. It is an angular breccia derived from Belt Supergroup rocks. Fields (1981) interprets it as fault gouge from the low angle normal Clark Fork Fault 3/4 of a mile north.

The Renova equivalent was deposited in an internally drained basin with a semiarid climate. Throughgoing drainages were inadequate to remove the high rate of sediment production. Volcanic ash was provided by local sources such as the Lolo Hot Springs volcanic center (Werhenberg, 1983) and the middle Tertiary Cascade rhyolite volcanic zone. Tremendous quantities of ash were concentrated by sheet floods running off surrounding uplands (Fields, 1985). Thompson and others (1982) state that the ash, and sediments produced from the highlands, were reworked by heavily loaded streams with braided channels. In addition, (Fields, 1981) reports that the environmental setting also included alluvial fan, playa, floodplain, overbank and coal swamp depositional sites.

The Sixmile Creek equivalent is separated from the Renova equivalent by an angular unconformity. It is a coarse clastic unit deposited between early middle Miocene (Hemingfordian/Barstovian boundary) and latest Miocene (Hemphillian) times (Thompson and others, 1982). The clastics were derived locally from developing fault-block mountains. Kuenzi and Fields (1971) describe the Sixmile Creek Formation in the Jefferson basin as having conglomerate as a major component on basin margins and centers. In the Missoula basin the Sixmile Creek equivalent is poorly exposed.

The Sixmile Creek equivalent in the Missoula basin is partially exposed in road cuts. It is not recorded in the Department of Energy wells in the Missoula basin, but is likely identified in wells MB-8, MB-9 and MB-12 on the east side of the Bitterroot basin (Fields, 1981). Water well logs record conspicuous amounts of "sand and gravel" which may represent Sixmile Creek sediments. A road cut on Upper Miller Creek road 2.6 miles south of US 93 exposes the formation. It is a poorly consolidated unit of cobbles and pebbles set in a sandy matrix. The clastics are about 90% Belt Supergroup quartzites and siltites and 10% Bitterroot Dom granites. The medium to fine grained sand is subangular and is composed of approximately 10% mica, 60% quartz and 30% feldspars. Some thin silty sand layers are also present.

Department of Energy test wells in the Bitterroot basin record the probable occurrence of the Sixmile Creek equivalent (Fields, 1981). An interval from 30 to 1200 feet in well MB-8 near Three Mile Creek is dominated by poorly consolidated pebble conglomerate and sandstone, with minor amounts of claystone and siltstone. The maximum clast size is 8 cm and the fine grained sand is angular to rounded. Fields (1981) interprets the deposital setting as a stream channel -- point bar sequence with slough and occasional overbank deposition. The interval is similar in lithologic character to local members of the Sixmile Creek Formation east of the Continental Divide and in the Drummond-Flint Creek Valley. Well MB-9 near Upper Three Mile Creek has an 80 foot interval similar in lithology to the MB-8 interval. Fields (1981) interprets an identical depositional setting possibly deposited by the ancestral Bitterroot River. Well MB-11 at Hamilton Bridge records 2,416 feet of sediment with no significant lithologic changes. Arkosic sands and ground-up granitic chips dominate the cuttings. Fields (1981) states that probably the entire thickness represents braided stream deposition of the ancestral Bitterroot River. He provides three possible designations to the interval: 1) Pleistocene gravels related to glacial outwash, 2) the Sixmile Creek equivalent in entirety, or 3) the ground-up granite floor of the Bitterroot Valley.

From the Department of Energy well logs, infrequent local outcrops and information from other Western Montana basins, several Sixmile Creek depositional environments are recognized. In the Missoula basin sediments of the Sixmile Creek equivalent accumulated in an undrained basin. The climate was arid and sediment was transported across desert plain surfaces. Locally, a remnant pediment in the South Hills area represents a sediment transport surface probably active in Sixmile Creek time. Thompson and others (1982) generalize the Sixmile Creek Formation as including fanglomerates, and evaporites and limestones that appear to be playa deposits. Fields and others (1985) state that the depositional environment included alluvial fans, mudflows, debris flows and ephemeral stream deposits. Sediments designated as probably Sixmile Creek in the Bitterroot basin record deposition from braided streams and stream channel -- point bar sequences. It is most likely that all these environments were involved in deposition of the Sixmile Creek Formation equivalent.

The Quaternary Period in the Missoula basin was greatly influenced by Pleistocene glaciation. Shoreline traces on Mounts Sentinel and Jumbo, lacustrine silts, and erratics on Water Works

Hill record the existence of Glacial Lake Missoula. Werhenberg (1983) roughly places Glacial Lake Missoula into the Bull Lake and/or Pinedale glacial episodes. An ice dam in the Pend d'Oreille trough periodically blocked the Clark Fork River near Noxon, Montana. When water behind the dam built up to sufficiently float the ice, catastrophic flooding occurred. At least 36 lake fillings are recorded in the basin's lake sediments and at least 38 floods are recorded in the depositional and erosional features in Eastern Washington (Werhenberg, 1983). Valley glaciers, most notably in the Grant Creek and Rattlesnake Creek drainages, deposited lateral and terminal moraines, and glaciofluvial sediments in the valleys.

Glacial Lake Missoula lacustrine deposits are well exposed in a road cut 1 mile east of Frenchtown, Montana and in a railroad cut west of Deer Creek road in Hellgate Canyon. Sequences of varved silts and calcite crystals, derived from glacial flour of the Precambrian Wallace and Helena Formations, are present. In addition pebble and sand layers with silt chips suggest stream deposition across the silt deposits at times of lake lowering. Elsewhere in the basin, particularly in the center, Lake Missoula silts were removed by post-Pindale fluvial processes.

DEPOSITIONAL HISTORY

The Tertiary paleoclimate is documented in the types and patterns of sedimentation. The basin-fill deposition was a result of a regionally consistent arid to semiarid climate. Basin filling was initiated by increasing climatic aridity. Throughgoing drainages were defeated and sediment accumulated. Schumm (1968) states that the combination of low rainfall and high evaporative rates leads to the scarcity of vegetation, which in turn leads to high rates of sediment production. However, during higher rainfall intervals, protective vegetation is established in mountainous regions, and an integrated drainage net instigates sediment evacuation.

In the Missoula basin and other Tertiary basins of Western

Montana and Eastern Idaho, regional unconformities bound the Renova and Sixmile Creek Formations. These episodes are interpreted to represent the lower limit of time of change from dry basin-filling regimes to relatively wetter basin-evacuating regimes (Thompson and others, 1982). In an analysis of over 200 Tertiary sediment samples, Thompson and others (1982) report strong correlations between climate and clay mineralogy. Arid climates produce smectite-rich soils, whereas wet climates produce kaolinite-rich soils. The paleosoils underlying the two unconformities are kaolinite-rich and appear to be laterite soils. The red laterite paleosoil may be exposed along I-90 north of Missoula. The clay mineralogy of both the Renova and Sixmile Creek Formations is exclusively smectite (Thompson and others, 1982). This evidence suggests Tertiary basin filling during aridity, or semiaridity, and evacuation during wetter climatic regimes.

The Missoula basin was delineated by Paleocene to Eocene Laramide intra-arc extension. The basin was shallow and development was progressive. Regional and local igneous activity provided ash-fall tuffs which choked drainages (Fields and others, 1985). Along the fault-bounded flanks of the basin coarse clastics accumulated (Fields, 1981). The climate was relatively wet and warm.

In late Eocene time a major change in climatic conditions occurred. This relatively arid cycle instigated intermittent deposition of the Renova Formation equivalent. At least 3000 and up to 13,000 feet of sediment was deposited (McMurtrey et al., 1965). In Middle Eocene through Early Oligocene times the basin rapidly subsided and abundant volcanic ash clogged through-flowing streams (Fields and others, 1985). Lacustrine and paludal conditions produced coal swamps which are recorded as lignite on the northeast side of the basin. By late Early Oligocene time internal drainage was firmly established. Air-borne ash, probably from the Cascade volcanic zone, was reworked by sheet-wash, mudflows and braided streams. From Early to Late

Oligocene ash-rich sediments were deposited in fluvial, lacustrine and paludal environments (Fields and others, 1985). In Early Miocene aridity increased and desert-like geologic processes dominated. Eventually, the mountains surrounding the basin filled the basin with their debris.

In early Miocene a dramatic climatic shift produced wetter conditions (Thompson and others, 1982). External drainage was initiated as the basins filled with water. Spillways connected the Missoula basin with the Bitterroot and the Drummond-Flint Creek basins. Renewed extensional faulting and folding tilted the Renova equivalent sediments (Fields and others, 1985). Vast quantities of the sediment were removed from the basin. The sediments remaining were deeply dissected and a "bad lands" topography existed. Although not defined in the Department of Energy wells, a red laterite paleosoil likely developed on the new topography. By the close of this 1 to 5 million year interval, the Missoula basin took on its modern appearance.

About 17 million years ago aridity again prevailed. This arid cycle lasted through Late Miocene time (Thompson and others, 1982). External drainage was defeated due to high sediment production rates from the sparsely vegetated basin. The former topography was buried by gravels and sands and large bajadas extended basinward from the valley flanks. Torrential surface runoff sent mudflows and sheet floods across the modified topography. High ephemeral stream gradients from continued uplift of the surrounding fault-block mountains carried and redeposited coarse sediments (Fields and others, 1985). The Missoula basin gradually filled, perhaps to the base of the hanging valleys on Mount Sentinel where gravel deposits are still present.

In latest Miocene -- Pliocene time the climatic pattern changed from dry to wet (Thompson and others, 1982). The Missoula basin was partially filled with coarse sediments and probably had a desert-like landscape. Renewed faulting uplifted adjacent ranges and precipitation increased, at least partially, due to the orographic influence (Fields and others, 1985). The increased precipitation again filled the basin and adjoining basins with water which eventually reestablished external drainage. Late Pliocene (?) lowering of the base level at Alberton Narrows was accompanied by sediment removal (McMurtrey and others, 1965). Sediment was removed from, and transported through, the Missoula basin. The fault-line scarp on Mounts Sentinel and Jumbo was exhumed. Pedimentation was extensive and a pediment is partially preserved today in the South Hills area.

In the Quaternary Period multiple glacial and interglacial periods produced alternating wet and dry climatic conditions. In wet periods the CFR carried large volumes of melt water. It carved its way into the former topography. Glacial Lake Missoula inundated the basin at least 36 times and deposited silts, ice-rafted erratics and a thin mantle of shoreline sediments. The lake probably only occupied the individual shorelines for several months. The Clark Fork River continued to remove and redeposit sediment transported through the basin. The coarse Pleistocene gravels are indistinguishable from Sixmile Creek equivalent gravels. Lacustrine silts were eroded from the basin center. Continued lowering of the river's base level produced two terrace surfaces. McMurtrey and others (1965) report that approximately 300 feet of alluvium was deposited in the Quaternary Period.

APPENDIX H

HYDROLOGIC PROPERTIES OF THE AQUIFER

Hydraulic properties of Unit One were derived from the permeameter and sieve data. The result of the permeameter experiment provided the only measured value of porosity available for the Missoula Aquifer. In addition, it supplied values for specific yield, specific retention and hydraulic conductivity. The measured values are: 19.7% for porosity, 11.5% for specific yield, 8.2% for specific retention, and an average hydraulic conductivity of 10,370 gpd/ft^2.

The sieve analyses were intended to provide K values for the vadose zone, Unit One, possibly Unit Three and the river bed. Saturated hydraulic conductivity values computed with Slichter's (1899) method and Terzaghi's (1925) method vary over 2 orders of magnitude (Clark, 1986).

K values from sieve data
(x 10^5 gpd/ft^2)

Method	#1	#2	#3	#4
Slichter	3.57	51.52	114.34	65.53
Terzaghi	0.03	0.03	1.79	0.03

The mean and effective grain diameters of samples varied from 400 to 800% which accounts for the large differences in calculated values between methods. An average K value for the four samples computed with both methods is 2,953,710 gpd/ft^2.

Grimestad (1977) reported hydraulic conductivity values of 10,250 gpd/ft^2 for the surficial gravel which corresponds to Unit One. He also calculated a specific yield of 0.2 to 0.35.

Hydraulic properties of Unit Two were interpreted from incomplete aquifer test data found on drillers's logs. Morgan (1986) reported specific capacity data from a small number of wells finished in what he interpreted as the finer middle unit. He reported an average value of 7 gpm/ft. Using estimating techniques described by Driscoll (1986), a representative transmissivity for the unit would be about 10,500 gpd/ft. The hydraulic conductivity would then be approximately 260 gpd/ft^2 based on an average thickness of 40 ft. Grimestad (1977) reported a hydraulic conductivity of 150 gpd/ft^2 for sediments interpreted as Unit Two.

Unit Three hydraulic properties were obtained from analysis of drillers's reports and aquifer testing. The properties of Unit One were also evaluated and compared to hydraulic properties derived for Unit Three. Transmissivity estimates based on well log specific capacity data were performed (Walton, 1970). Transmissivity values range from 52 to 4,149,000 gpd/ft for domestic wells and average 365,600 gpd/ft. Values for municipal wells range from 48,000 to 9,752,000 gpd/ft and average 1,710,000 gpd/ft. An average value of transmissivity for both municipal and domestic wells is 750,000 gpd/ft. Hydraulic conductivity values for municipal wells range from 520 to 113,400 gpd/ft^2 and average 25,500 gpd/ft^2. Values for domestic wells range from 1 to 27,700 gpd/ft^2 and average 4,100 gpd/ft^2. The average value for both municipal and domestic wells is 10,300 gpd/ft^2.

Morgan (1986) reported specific capacity data for over 50 wells and found an average specific capacity value of 240 for Unit Three wells. Estimation of K and T from these data yields a range of K between 3,600 and 7,200 gpd/ft^2 and a T of 360,000 gpd/ft (Driscoll, 1986).

The distribution of K and T values were evaluated for the Missoula area. The only pattern which appeared to emerge is that the western portion of the study area has lower values. Data could be interpreted to show hydraulic conductivity and to southwest towards the central portion of the valley to be up to an order of magnitude higher than in other portions of the valley.

Hydraulic conductivity and transmissivity values generated from perforated aquifer intervals with known aquifer thickness, cable tool drilling methods, and pumping tests of at least four hours are assumed to provide the most accurate results. Transmissivity values from municipal wells (MWC) fit these criteria best and average 1,710,000 gpd/ft with and an average hydraulic conductivity of 25,500 gpd/ft^2.

This interpretation of the data describing the properties of Unit Three correlates well with previous work. McMurtrey and others (1965) determined transmissivity (T) values from specific capacity tests which vary from 17,800 to 1,000,000 gpd/ft. From an aquifer test at a well south of the Clark Fork River in the north central part of the study area they calculated a T value of 620,000 gpd/ft. Grimestad (1977) reported a K range of 3,400 to 16,660 gpd/ft^2 for the coarse sand and gravel at depth at his study area. He also reported that McMurtrey and others (1965) reported the transmissivity for two wells producing water from that unit to range from 77,000 to 125,000 gpd/ft. An aquifer test by Geldon (1979) provided a T value of 699,927 gpd/ft. Hydrometrics (1984) attempted an aquifer test on MWC-34 near the Clark Fork River and concluded that transmissivity ranged from 250,000 to 1,000,000 gpd/ft. From 19 aquifer tests Geldon (1979) reports an average K value of 680 ft/d. In the same test series he determined specific capacity values ranging from 3 to 3,000 gpm/ft. McMurtrey and others (1965) assumed a porosity value (n) of 0.40 and a specific yield (SY) of 0.10. Geldon (1979) found time-dependent SY values from aquifer tests. They ranged from 0.11 to 0.35.

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